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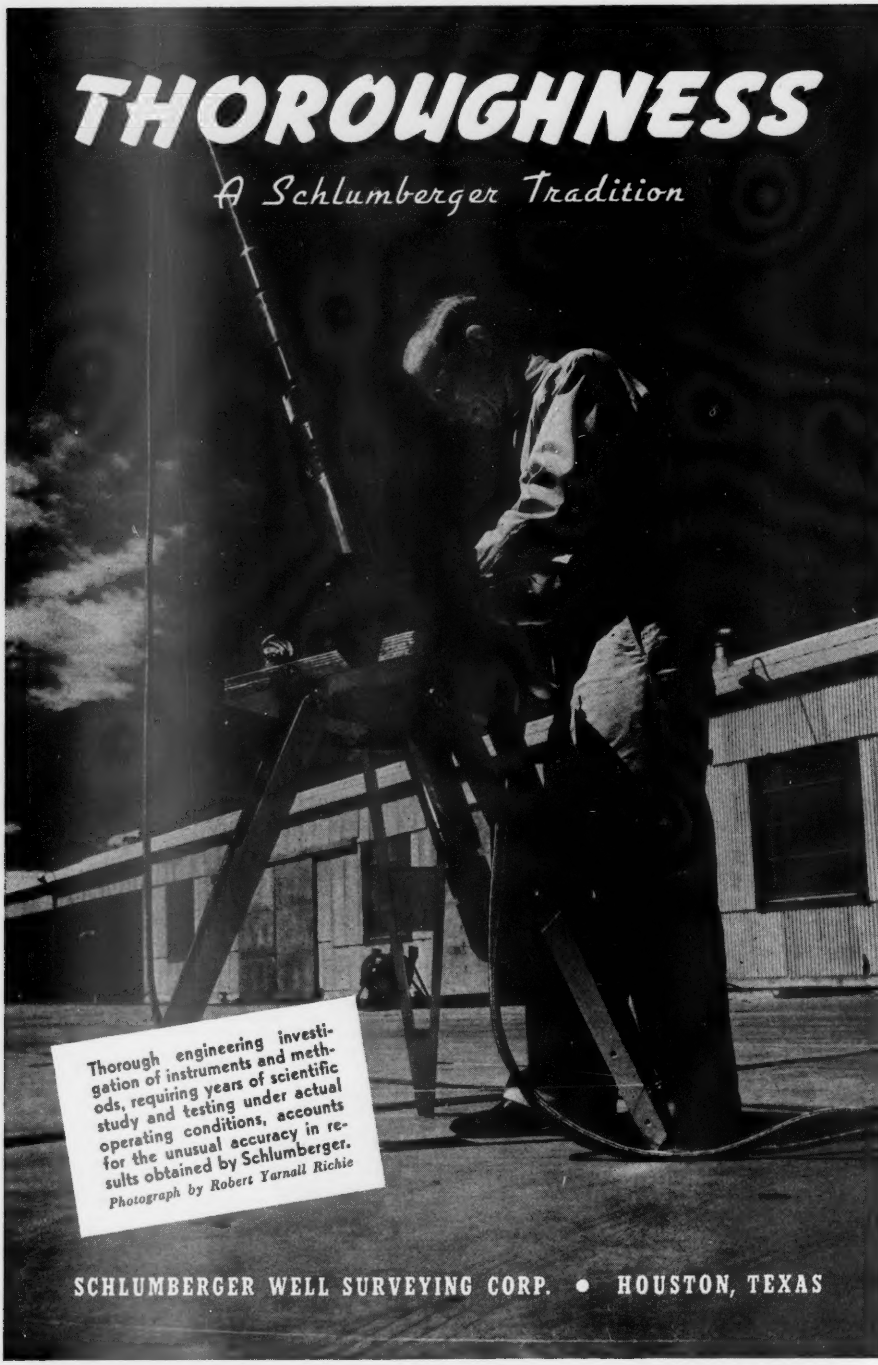
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NOVEMBER, 1941

OLIGOCENE STRATIGRAPHY OF EAST WHITE POINT FIELD, SAN PATRICIO AND NUECES COUNTIES, TEXAS[1]

PHIL F. MARTYN[2] AND CHARLES H. SAMPLE[3]
Houston, Texas

ABSTRACT

The East White Point oil field is located in south-central San Patricio and north-central Nueces counties, Texas, on the Gulf Coastal Plain of South Texas. It is situated approximately midway between Galveston and Brownsville, 20 miles inland from the Gulf of Mexico, and 5 miles northward across Nueces Bay from the city and deep-water port of Corpus Christi. Subsequent to the discovery of oil in the 5,600-foot sand, by the Plymouth Oil Company in February, 1938, the field has been subjected to continuous development. As of January 1, 1941, approximately 240 oil and gas wells have been completed in the four productive sands between the depths of 4,100 feet and 5,900 feet, which wells have yielded approximately $5\frac{1}{2}$ million barrels of oil.

Within the scope of this paper, the strata encountered in most of the wells below a depth of 4,000 feet have been grouped in the Oligocene formation, and the writers have restricted their study to the beds included in the interval below that depth and above the 5,600-foot (principal oil-producing) sand. Isopach and other geologic studies of the several sand and shale zones have presented interesting problems. The intermittent and periodic structure-making movements, and likewise the periods of quiescence, are reflected in the sedimentary intervals of the respective strata. The most outstanding feature of the stratigraphy, however, is the well developed erosional topography on the top of the 5,400-foot (Zone E) sand. Isopach maps of this stratum display the typical features of degradation and planation common to the erosion cycle of normal rivers in an area being subjected to cyclic rejuvenation. Similar maps of the overlying 5,300-foot (Zone D) shale reflect the effects of unequal deposition over the eroded topography. As suggested by the reconstructed terraces and slopes attendant thereto, three periods of uplift and erosion are present. The erosional unconformity thus established, and advocated by the writers, offers additional criteria and evidence for the following: first, offlap or regression of the Gulf of Mexico at the close of Frio time with the consequent development of stream drainage and erosional topography on the land surface; second, the location of an ancient Gulf of Mexico at some distance removed from the present location of the East White Point field following the deposition of the 5,400-foot sand; and third, the delineation of the top of the Frio formation at the erosional break in the stratigraphy.

INTRODUCTION

By contrast with the fact that the earliest discovery of oil or gas in

[1] Read before the Association at Houston, April 2, 1941. Manuscript received, April 21, 1941.

[2] Chief geologist, Houston Oil Company of Texas.

[3] Geologist, Houston Oil Company of Texas.

the Corpus Christi area of southwestern Gulf Coastal Texas was made in the White Point field of San Patricio County, Texas; more than three decades intervened between the discovery of gas and the manifestation of the prominence of the area as an oil-productive locality. The inference may be drawn from the nomenclature of the two producing areas that the White Point and East White Point fields are separated by location, structural influence, and other geological factors. On the contrary, this is not true, since the productive areas are, in part, synonymous; the structure is definitely interrelated, and other geologic features of sedimentation, stratigraphy, and topography are closely allied. The only differences between the two productive fields are: first, the principal development of the White Point field occurred prior to the year 1927, during the era of meager paleontologic information, unreliable well logs, and general lack of geologic data about the wells drilled, while all of the development of the East White Point field has taken place since 1938, under the careful guidance of geologists who used electrical logs and accurate sample and paleontologic information; second, the large majority of the wells completed in the White Point field were gas wells (four wells showed small quantities of oil) in contrast to the fact that 235 of the approximate 244 wells drilled in the East White Point field have been completed as oil wells, and are now producing; and third, the principal producing zones of the White Point field are found at depths above 5,000 feet as differentiated from the oil zones of the East White Point area now producing at depths ranging from 4,900 to 5,900 feet.

Strangely enough, since discovery in 1904, there have been few published data available about the structural, stratigraphic, or other geologic problems of the White Point field, and no published material has yet reached the attention of the writers with respect to the East White Point field. Deussen[4] presented a brief history of the White Point field in reviewing the oil developments of the Gulf Coast country in 1917. A brief history of the surface "showings" noted at the time of the first prospecting, the early gas development, and the initial discovery of oil in the White Point field have been outlined by Price[5] in a geological note in the *Bulletin*. In a paper read before the 1933 Houston meeting of the Association, Price[6] summarized the subsurface geology of the White Point field as follows.

[4] Alexander Deussen, "Review of Developments in the Gulf Coast Country in 1917," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 2 (1918), p. 35.

[5] W. Armstrong Price, "Discovery of Oil in White Point Gas Field, San Patricio County, Texas, and History of Field," *ibid.*, Vol. 15, No. 2 (February, 1931), p. 205.

[6] W. Armstrong Price, "Role of Diastrophism in Topography of Corpus Christi Area, South Texas," *ibid.*, Vol. 17, No. 8 (August, 1933), p. 907.

The White Point gas field has been contoured by the writer and others as a broad, dome-like nose whose southeast and southwest slopes are parallel with similar bluffs of the compound peninsula or inter-meander spur of White Point. Northwest closure is poorly, if at all, indicated by well logs. Subsurface contours drawn in such a manner that the minor details of surface topography were not in the mind of the geologist surprisingly revealed a coincidence between minor structural lows and the V-shaped valley-wall arroyos.[7]

Subsequently, in a paper by Getzendaner[8] read before the San Antonio section of the Association at the Corpus Christi meeting, the following summary of the structure of the White Point field was made.

White Point:—In the White Point field, though there are many wells, the logs are poor, deep wells are few, and the paleontologic information is inadequate. The geologist is therefore forced to rely largely on graphic well-log correlations in his preparation of a structural map. Such correlations suggest a pair of small domes, each with western closure.[9]

Additional drilling in the White Point field subsequent to the year 1933 and the entire development of the East White Point area since 1938, coupled with the use of electrical logs, paleontologic information, and more adequate coring methods and analyses, have rendered possible a more complete analysis of the structural and stratigraphic complexities of the two producing areas. Although structural problems are somewhat interdependent of stratigraphic relationships, the writers have deemed it advisable, within the scope of this paper, to make no mention of the structural influences unless such factors have a direct relation to the problems of sedimentation and stratigraphy of the Oligocene strata here discussed.

ACKNOWLEDGMENTS

The writers express their grateful acknowledgment to the officers and directors of the Houston Oil Company of Texas, which company has been actively engaged in the production of gas and oil from the White Point and East White Point fields, respectively, since 1925, for extending permission for the publication of this study; to associate geologists Maurice E. Forney and Laurence F. Dake, who have assisted in the compilation of geologic information and have aided in the preparation and drafting of the diagrams and maps; to Merle C. Israelsky, W. F. Bowman, and Lewis O. Kelsey for their helpful

[7] *Ibid.*, p. 951.

[8] A. E. Getzendaner, "McFaddin-O'Connor, Greta, Fox, Refugio, White Point, and Saxet Fields, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 4 (April, 1934), p. 519.

[9] *Ibid.*, p. 525.

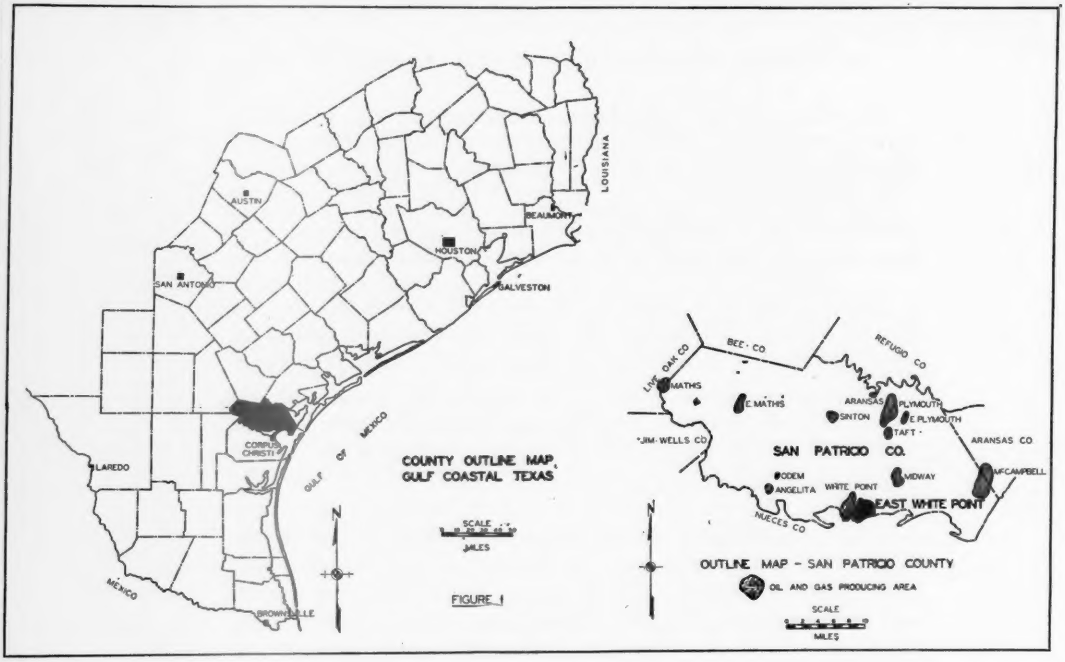

FIG. 1.—County outline map of Gulf Coastal Texas showing location of San Patricio County and map of San Patricio County indicating oil and gas productive fields.

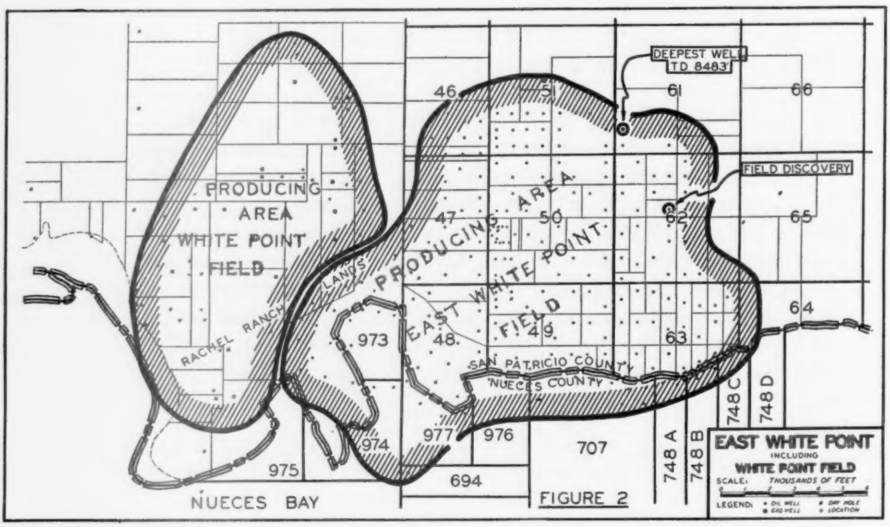

FIG. 2.—Oil and gas productive areas of White Point and East White Point fields. Map indicates also discovery well, deepest well, and section and survey numbers in East White Point field.

comments, suggestions and criticism; to the Plymouth Oil Company, the Sinclair Prairie Oil Company, the Republic Natural Gas Company, the Humble Oil and Refining Company, the Texas Company, the Killam Oil Company, the Shell Oil Company, Inc., the Stanolind Oil and Gas Company, the Shasta Oil Corporation, and others for permission to present the electrical logs used in the cross sections; and to the many other geologists and individuals who have furnished helpful data and assistance.

An early draft of this paper was presented before group meetings of the Houston Geological Society at Houston, Texas, the South Texas Geological Society at Corpus Christi, Texas, the Southwestern Geological Society at Austin, Texas, and the Dallas Petroleum Geologists at Dallas, Texas, during the early months of 1941. The writers acknowledge their indebtedness to the many geologists in attendance at these meetings for their candid discussion of the idea presented. Pertinent and helpful data from the discussions were of practical value in the final compilation of this manuscript.

LOCATION

The East White Point oil and gas field is on the north shore of the Nueces Bay in the southern part of San Patricio County and the northern part of Nueces County, Texas, in the Gulf Coastal Plain of South Texas. These counties are approximately midway between Brownsville and Galveston. The field is approximately 190 miles southwest of Houston, 125 miles southeast of San Antonio, 20 miles inland from the Gulf of Mexico, and 5 miles northward across the Nueces Bay from the city and deep-water port of Corpus Christi.

Figure 1 is a county outline map of the Gulf Coastal area of Texas on which the location of San Patricio County is indicated, with a county outline map showing the producing areas. The East White Point field is east of, and adjacent to, the White Point field, and the productive areas of the two fields overlap each other along their common boundary.

The productive area of the East White Point field centers in Section 50 and includes parts of Secs. 46, 47, 48, 49, 50, 51, 61, 62, 63, and the Rachel Ranch lands of San Patricio County and State Surveys 694, 707, 748-A, 748-B, 973, 974, 975, 976, and 977 of Nueces County (Fig. 2). The north shore line of the Nueces Bay (Fig. 2) marks the boundary between San Patricio and Nueces counties. Drilling and development of the productive part of the field in Nueces County, on the submerged lands of the Nueces Bay, have been limited and the larger part of the present oil-productive area, therefore, is now included in San Patricio County.

The field derives its name from the location of the productive area east of the older White Point oil and gas field. Both field names retain the nomenclature of the topographically high, peninsula-type promontory extending southward into the Nueces Bay at the south end of the White Point field (Fig. 2). Price[10] has included the White Point peninsula portion of the Corpus Christi Quadrangle and part of the adjoining Robstown Quadrangle in illustrating the drowned valley of the Nueces River in the White Point area.

The reader's attention is called to Figure 2 with particular reference to the Section numbers of lands in San Patricio County, to the location of the Nueces-San Patricio County line, to the submerged lands in the Nueces Bay, and to the Survey numbers of the State lands located in Nueces County. In the presentation of the many isopach maps in this study, the writers have found it desirable and necessary to omit as much detail as could be wisely eliminated from the base maps on which the isopach maps were prepared. Future references within this paper, in the discussion of the isopach maps, will be made to Survey and Section numbers of certain lands for the purpose of locating the foci of the stratigraphic and structural features, and the reader may find it desirable to recall this map (Fig. 2) as a handy reminder for the locating of the salient points of geologic interest.

DISCOVERY AND HISTORY

In the decade following the discovery of oil in the Gulf Coast of Texas at Spindletop in 1901, many of the topographic features of the Coastal area were investigated by drilling. The first development in the White Point area was begun in 1904 by Randolph Robertson on the high scarp on the west side of White's Point. It is recorded that the unusual topography, coupled with gas showings in shallow water wells and springs and disseminated sulphur grains in the surface sediments as shown by Price,[11] suggested the presence and possibility of a salt dome in the White Point area. The first well reached a depth of approximately 450 feet, encountered several showings of gas, and was abandoned at that depth. A second well by Robertson, drilled to 150 feet, and a well by Lee Hager, drilled to 1,200 feet, were abandoned during the years 1904 and 1905. The initial discovery of commercial gas may be attributed to the White Point Oil and Gas Company in its developments on the Rachel lands during 1911, inasmuch as the two wells drilled by this company showed large quantities of gas in sands

[10] W. Armstrong Price, *op. cit.*, p. 950.

[11] W. Armstrong Price, *op. cit.*, Vol. 15, No. 2 (February, 1931), p. 205.

at depths of 1,600 feet and 1,900 feet, respectively, although both wells were lost as blow-outs and craters due to mechanical difficulties.

In the interim, subsequent to discovery in 1911 and prior to 1938, the White Point field was subjected to intermittent and sporadic development. During the period from 1913 to 1918, several wells were drilled in the area by the Gulf Production Company and others, the most of which were abandoned as blow-outs and craters, but two wells were successfully completed as gas wells. The period from 1925 to 1928 marked the principal era of development in the White Point area. Many gas wells were completed, and two gas pipe lines were laid from the field. There has been little activity in the locality since the latter date.

Following a detailed seismograph geophysical survey of the area east of the White Point field, a well was drilled during 1936 by M. E. Davis *et al.* on the C. V. Jones property. This well reported no showings of oil or gas, and was abandoned at a total depth of 6,348 feet in May, 1936. Based on subsurface geological data from the Davis well and on other geophysical data, the Plymouth Oil Company commenced the drilling of its Brigham No. 1, in December, 1937. This well, located near the center of Section 62 (Fig. 2), was drilled to a total depth of 5,665 feet, and was completed as the discovery well of the East White Point field on February 25, 1938, through casing perforations at a depth of 5,661–5,664.5 feet, with an initial daily production of 217 barrels of pipe-line oil through a 9/64-inch choke, holding 950 pounds working pressure on tubing and 1,100 pounds shut-in pressure on casing, and producing with a gas-oil ratio of 305 cubic feet of gas per barrel of oil. Continuous and progressive development of the field, since discovery, has been maintained and, on March 1, 1941, a total of approximately 250 wells had been drilled. Of this number, four were completed as gas wells in the 4,100-foot sand; one was completed as an oil well in the 4,900-foot sand; two were brought in as oil wells from the 5,800-foot sand; and 232 wells were oil producers from the 5,600-foot sand. Total oil production to January 1, 1941, was approximately $5\frac{1}{2}$ million barrels.

PHYSIOGRAPHY

The physiographic features of the White Point and East White Point area have been described by Price[12] who suggests the possibility of the drowning of the Nueces Valley with the consequent forming of the Nueces Bay, and describes the topographically prominent White

[12] W. Armstrong Price, *op. cit.*, Vol. 17, No. 8 (August, 1933), pp. 907 *et seq.*

Point peninsula as an inter-meander spur, the remnant of an erosion cycle of an older Nueces River.

By reference to topographic sheets,[13] it may be noted that the East White Point field is located on the wave-cut terrace on the north side of the Nueces Bay. This terrace, sloping eastward at the rate of 2-4 feet per mile, varies in elevation from 40 to 60 feet in the producing area of the field. Elevations in the proved field area vary from sea-level at the tide water of the Nueces Bay to approximately 65 feet on the upland terrace. Recent uplift in the area is suggested physiographically, by the following evidence: (1) the abnormally high eleva-

TABLE I

STRATIGRAPHIC COLUMN, EAST WHITE POINT FIELD, TEXAS

	Formation	*Thickness in Feet*
PLEISTOCENE	Beaumont clay, Lissie sand, Goliad formation } Undifferentiated	2,100
PLIOCENE ? MIOCENE	Lagarto clays	900
MIOCENE	Oakville sands	500
OLIGOCENE	Catahoula	2,000
	Frio	3,000+
	Vicksburg (*Textularia warreni* zone)	Not yet penetrated

tion of the Beaumont clay terrace in the locality of the White Point and East White Point fields, considered by the writers to be approximately 15-20 feet in excess of normal; (2) the development of youthful drainage (Gum Hollow and other intermittent streams) northward into the higher topography from the wave-cut terrace along the Nueces Bay front; and (3) drainage from the area reaches the Gulf by a circuitous route, since rainfall on the producing area flows northward for several miles into the drainage channels of Chiltipin Creek, instead of flowing southward a very short distance into the Nueces Bay.

The area locally is only very sparsely wooded with the typical South Texas brush, and, by reason of the outcrop of the Beaumont clay, it is especially suitable as farm lands. The principal farm crop is cotton, although truck farming has been conducted with moderate success. The approximate mean annual rainfall and temperature are 30 inches and 71° F., respectively, as a consequence of which the territory is subjected to normal semi-arid geological processes.

[13] "Corpus Christi" and "Robstown," *U. S. Geol. Survey Topog. Quadrangles.*

STRATIGRAPHY

The surface materials exposed in the East White Point field area are classed as being Beaumont in age. This formation consists of gray, buff, tan and red, calcareous, gypsiferous clays which weather to rich, black, waxy, tillable farm land.

A fairly complete stratigraphic column of the East White Point field is presented in Table I. During recent years, a more complete knowledge of subsurface stratigraphy has been made available to geologists and numerous revisions have been made. A slight revision in the stratigraphy is suggested in the final conclusions of this paper. All of

TABLE II
OLIGOCENE STRATIGRAPHIC COLUMN, EAST WHITE POINT FIELD, TEXAS

Formation		Nomenclature of This Paper	Thickness in Feet
Upper Catahoula			500
		Unconformity	
Middle Catahoula	"*Discorbis* sand"	4,100-foot sand—Zone A	370–560
	Shale zone	4,500-foot shale—Zone B	400–440
	"*Heterostegina* sand" (Greta)	4,900-foot sand—Zone C	190–380
Lower Catahoula shale zone		5,300-foot shale—Zone D	10–200
		Unconformity	
Frio	Sand zone	5,400-foot sand—Zone E	50–430
	Shale zone	5,500-foot shale—Zone F	40–150
	Sand zone	5,600-foot sand	50–150
	Sands and shales		2,800'+

these revisions, particularly with respect to parts of the Oligocene, are incorporated in Table I. The oldest formation penetrated by the deepest well is the lower part of the Frio formation, Oligocene in age. The field's deepest well is the Plymouth Oil Company's Brooks No. 3 (Fig. 2), which was plugged back and completed at a depth of 4,010 feet after being drilled to the total depth of 8,483 feet.

The stratigraphic column presented in Table I has been generalized with respect to the portion of the Oligocene discussed in this paper. For that reason, the writers desire to acquaint the reader with the subdivisions of those formations and their nomenclature as used throughout this paper. These are presented in Table II.

Oil and gas in the East White Point field is produced from sands of Oligocene age. Gas is presently being produced from the "*Discorbis* sand" (4,100-foot sand—Zone A of Table II) and oil is produced from the "*Heterostegina* sand" (Greta) (4,900-foot sand—Zone C of Table II), the 5,600-foot sand (5,600-foot sand of Table II), and the 5,800-foot sand. The strata above the 4,100-foot sand (Zone A) and below the 5,600-foot sand are definitely Oligocene in age, but within the

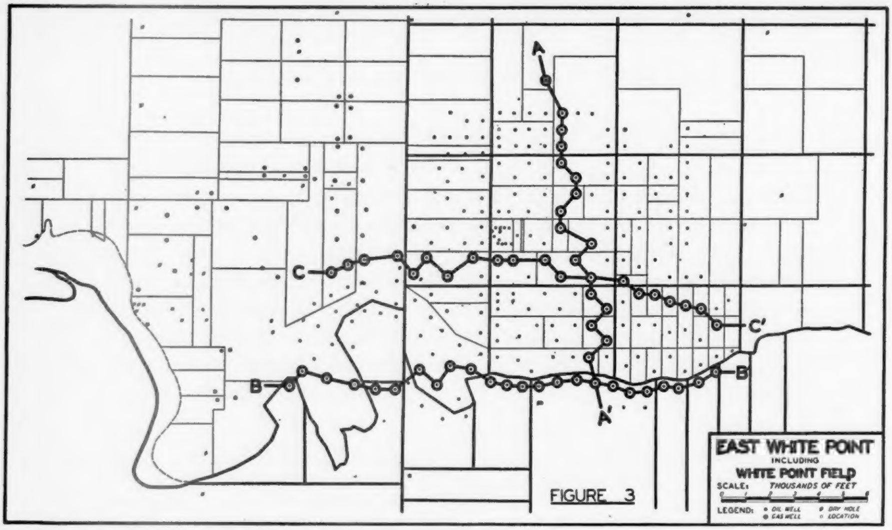

FIG. 3.—Map of East White Point field showing alignment of cross sections *AA'*, *BB'*, and *CC'*.

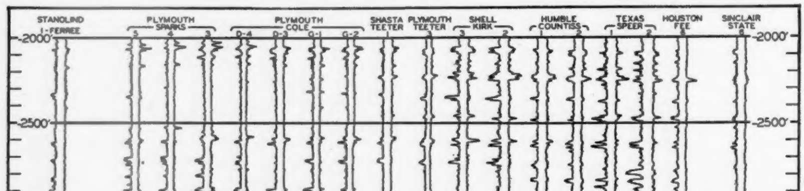

FIG. 4.—North-south cross section *AA'*, using electrical logs, indicating variations in intervals between respective correlative horizons of Oligocene strata.

scope of this paper only those strata between the top of the 4,100-foot sand (Zone A) and the top of the 5,600-foot sand are analyzed with respect to the stratigraphic problems involved.

In the study necessary for a complete knowledge of the structural, stratigraphic, and oil- and gas-accumulation problems of the East White Point field, the writers noted outstanding differences in stratigraphy and sedimentation with respect to wells drilled in various parts of the productive area. Three cross sections of the producing area have been prepared to exemplify this controversial point. The alignment of the sections is shown in Figure 3. By comparison with Figure 2, it may be noted that section *AA′* traverses the field from north to south, extending from Section 51 in San Patricio County to State Survey 707 in Nueces County; that sections *BB′* and *CC′* cross the producing area from west to east, and extend, respectively, from the Rachel Ranch lands in San Patricio County to State Survey 748-B in Nueces County, and from the Rachel Ranch lands to Section 63 in San Patricio County. Section *CC′* was so chosen that it might approximately bisect the structural uplift and the producing area. All sections have been prepared from electrical logs exclusively, and all are drawn to the same horizontal and vertical scale. In order to accentuate the correlations of the sedimentary intervals, the between-well correlations are indicated, and the sand zones are shown in solid black.

Section *AA′* is shown in Figure 4. Only minor variations in the stratigraphy may be noted from this section because of its apparent parallelism with the sedimentary strike of the formations. The variations are: first, a gentle southward thickening of the 4,100-foot sand (Zone A) with a local variation in the locality of the Humble Oil and Refining Company's Countiss No. 1; second, a slight thinning of the 4,900-foot sand (Zone C) from north to south; third, a local thinning of the 5,300-foot shale (Zone D) south of The Texas Company's Speer No. 1, equally compensated by local thickening of the 5,400-foot sand (Zone E) southward from the same well; and fourth, moderate increase in interval of the 5,500-foot shale (Zone F) from south to north across the field.

Section *BB′* is presented in Figure 5, and clearly illustrates the perplexing variations in stratigraphy formerly noted. The stratigraphic changes are: first, an increase in thickness of the 4,100-foot sand (Zone A) in the localized area of the Sinclair Prairie Oil Company's No. 3, State Survey 707; second, progressive and continuous thickening of the 4,900-foot sand (Zone C) from east to west; third, westward thinning of the 5,400-foot sand (Zone E) over the whole area, in part compensated by the westward increase in thickness of the 5,300-foot shale

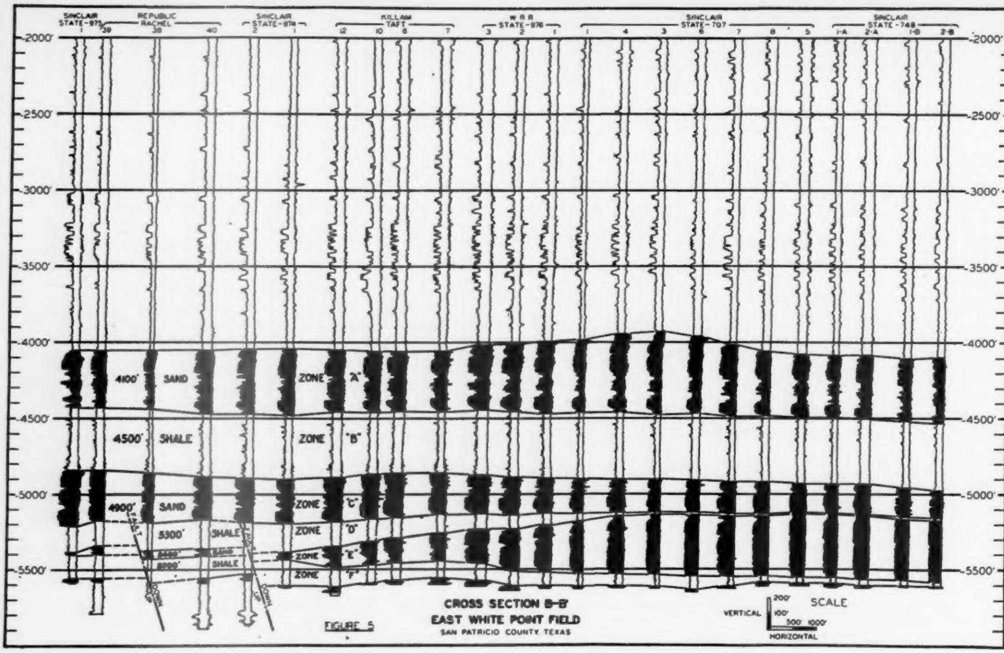

FIG. 5.—West-east cross section *BB′*, using electrical logs, indicating interval variations of some Oligocene strata.

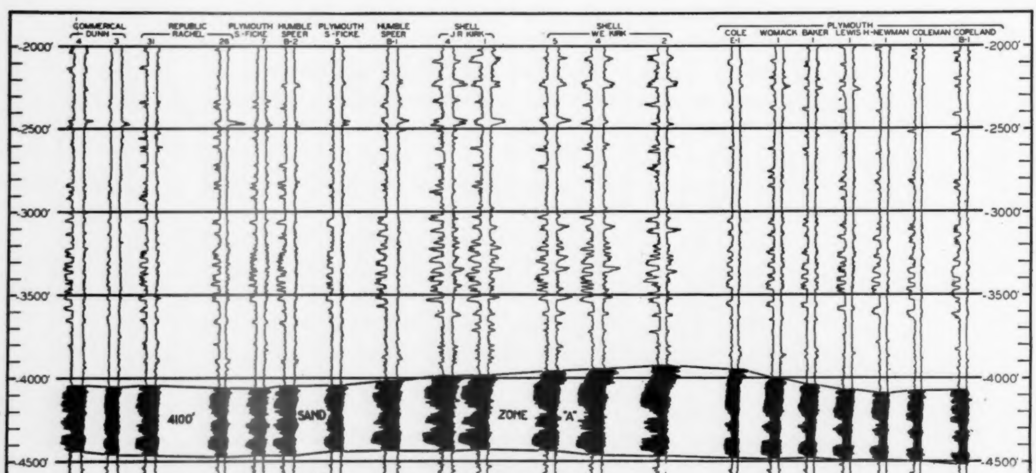

FIG. 6.—West-east cross section *CC′*, using electrical logs, indicating interval variations of some Oligocene strata.

(Zone D); and fourth, gentle westward thickening of the 5,500-foot shale. Two normal faults, upthrown on the west, are diagrammatically shown. Many small faults occur in the western part of the producing area, but only those reflected in the electrical logs, as affecting the interval changes of the strata here studied, are so shown on the sections.

Figure 6 is the cross section along the alignment *CC′*. The conspicuous stratigraphic variations of this section are: first, increase in thickness of the 4,100-foot sand (Zone A) in the locality of the Shell Oil Company's W. E. Kirk No. 2, and localized thinning of the same zone toward the east and west; second, progressive westward increase in thickness of the 4,900-foot sand across the field (Zone C); third, prominent westward thinning of the 5,400-foot sand (Zone E) and, as in section *BB* (Fig. 5), complementary to a westward thickening of the 5,300-foot shale (Zone D); and fourth, the gentle westward increase in thickness of the 5,500-foot shale (Zone F). A small normal fault, similar to those previously described, is shown in section *CC′*.

For a handy reference and a clearer understanding of the sand and shale strata a generalized diagrammatic west-east section of the East White Point field is presented in Figure 7. Isopach maps of the various zones and combinations of zones are shown in subsequent maps in this paper. All isopach maps are drawn to the same scale and all isopach intervals are 10 feet, with the 50-foot divisions shown by heavier lines properly numbered. Unless otherwise shown, all maps are oriented true north, and, where possible, the isopach intervals affected by the numerous small faults in the western part of the productive area are omitted from the final compilation.

As may be noted on Figures 4, 5, and 6, accurate correlations of sand and shale intervals can be made from the electrical well logs. In the East White Point field, electrical logs were available for practically every well. The basis of this stratigraphic study has been the correlation of the sand and shale intervals as interpreted from the electrical logs. In a paper read before the Association at the New Orleans meeting, 1938, the senior writer[14] made certain general assumptions for the interpretation of variations of stratigraphic and sedimentary intervals in the Refugio field. Those assumptions and others pertinent to the study of the East White Point field are used as a basis for the understanding of the problems here presented. These assumptions are the following.

1. Under normal geological processes and conditions, constant and uniform horizontal and vertical deposition of sediments prevails in

[14] Phil F. Martyn, "Refugio Oil and Gas Field, Refugio County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 9 (September, 1938), p. 1199.

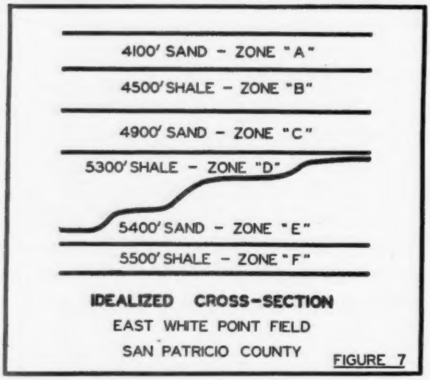

FIG. 7.—Idealized diagrammatic west-east cross section of East White Point field showing sand and shale strata and their respective zonal names, as discussed in this paper.

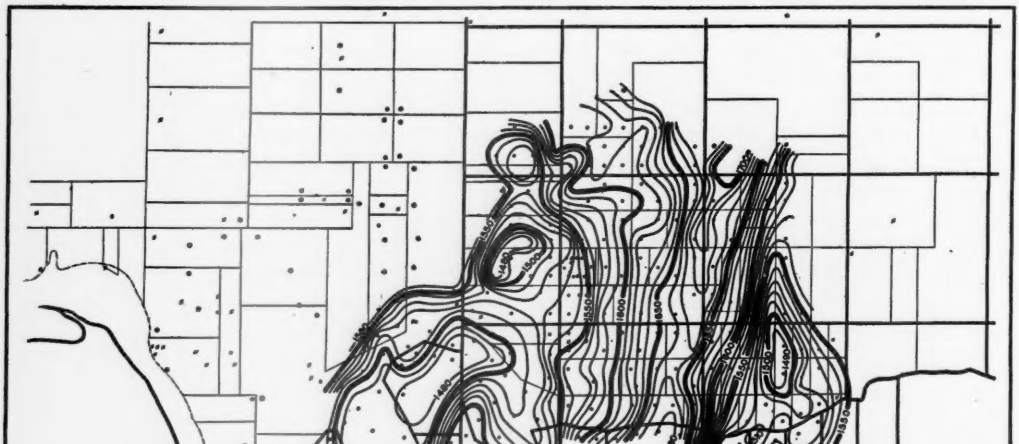

FIG. 8.—Isopach map of interval from top of 4,100-foot sand to base of 5,500-foot shale (zones A, B, C, D, E, and F).

any very restricted area, such as that now occupied by the East White Point field.

2. The close of deposition of any sedimentary unit or cycle may be considered as a plane at the close of the respective deposition.

3. The period or date of the structural uplift may be determined, associated, and connected with the sedimentary interval affected.

4. Structural uplifts are reflected in the stratigraphic column by a shortened interval or hiatus, that is, the uplifted area during any sedimentary geologic period is evidenced by missing beds and a short section.

5. Sand zones or stratigraphic sand units, where the upper or any restricted portion of such zone produces oil or gas, may be used as correlative horizons. It is assumed that conditions in and adjacent to such restricted reservoir beds have been, in the geologic past, favorable for the generation, preservation, and retention of the oil and gas in the interstitial spaces of the sands. The writers realize that such sand zones were probably deposited near shore on a slightly tilted plane, but have neglected this minor variation of interval in this paper. Three of the four sand units, used in this study of the East White Point field, are commercially productive of oil or gas.

Figure 8 presents an isopach map on the interval from the top of the 4,100-foot sand to the top of the 5,600-foots and (zones A, B, C, D, E, and F). This map can be interpreted as a structural picture for the 5,600-foot sand coincident with the close of deposition of the 4,100-foot sand. The map presents evidence for the following deductions about structure and stratigraphy: first, a structurally positive area of 210 feet uplift centering in Section 63 on the east flank of the field; second, a similar, but larger, structurally positive area of 220 feet uplift trending northeast-southwest across the western part of the field from the north corner of State Survey 975 to the southwest corner of Section 51; third, a structurally low area or trough, located between the two positive areas, with 210 feet of relative subsidence and trending northeast-southwest from the southwest quarter of Section 61 to the northwest quarter of State Survey 707; and fourth, minor differences, due to faulting, are shown by the irregularities of interval in Sections 46 and 51 on the northern side of the field.

Figure 9 presents an isopach map of the interval from the top of the 4,100-foot sand to the top of the 4,900-foot sand (zones A and B). This map illustrates the location and amount of relative uplift or subsidence in the East White Point field area during the deposition of these strata. Evidence is again suggested for the two structurally positive areas and the structural trough or low area between the two

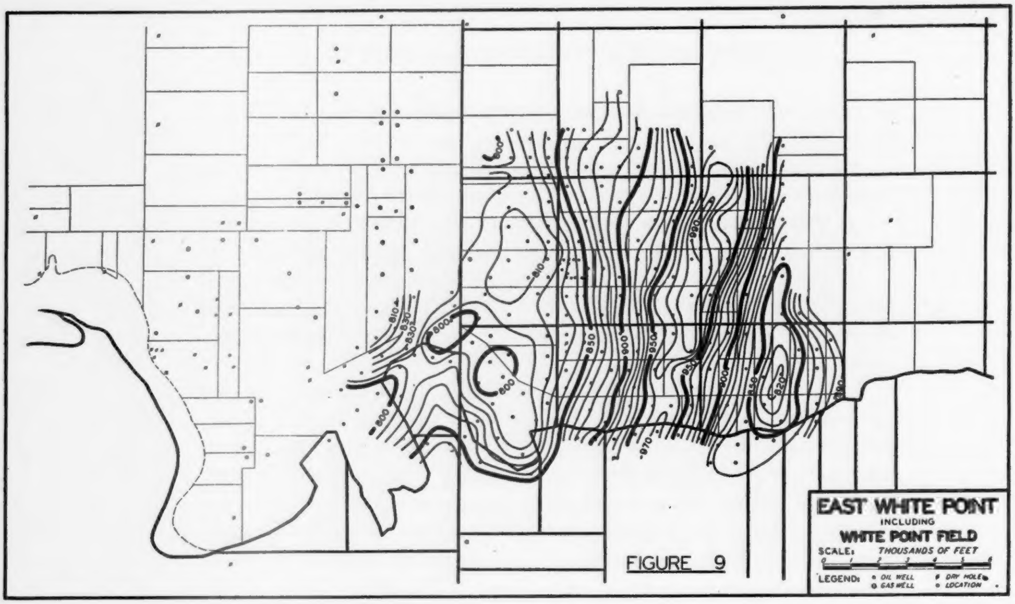

FIG. 9.—Isopach map of interval from top of 4,100-foot sand to top of 4,900-foot sand (zones A and B).

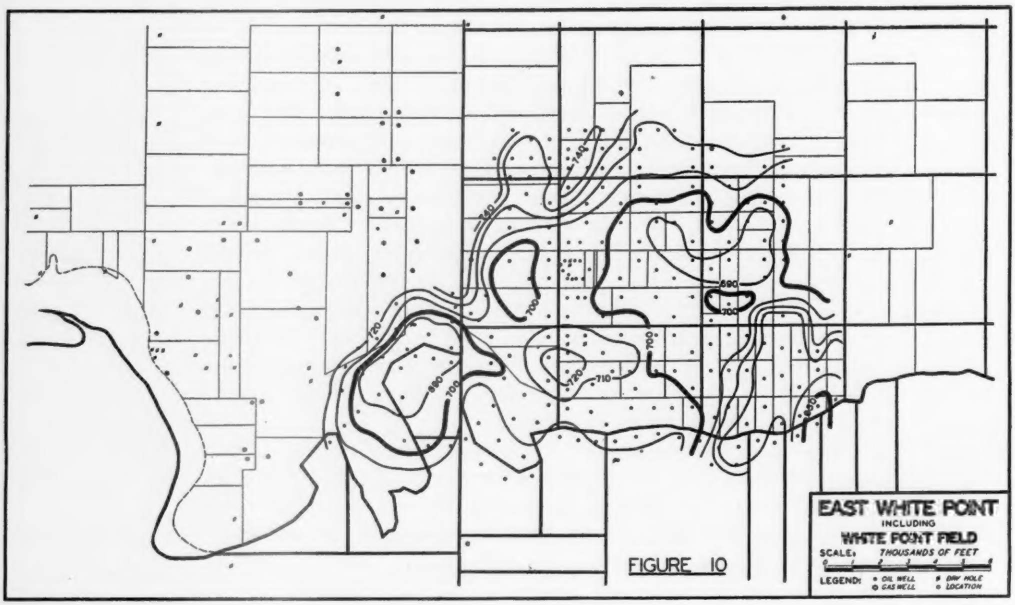

FIG. 10.—Isopach map of interval from top of 4,900-foot sand to base of 5,500-foot shale (zones C, D, E, and F).

"highs" coincident in location with the same geologic features suggested by Figure 8. It is to be noted that, of the approximately 210 feet of structural uplift suggested on the positive areas on the east and west sides of the field in Figure 8, at least 170 feet or more of this uplift occurred during the deposition of the interval of Figure 9. The reader should bear in mind the location and direction of trend of the structurally positive areas for comparison with data to be subsequently presented.

Figure 10 represents the structural interpretation of the 5,600-foot sand at the close of 4,900-foot sand deposition, and, therefore, presents an isopach map of that interval (zones C, D, E, and F). The structurally positive areas, previously shown in Figures 8 and 9, are supported by these data, but of less magnitude. The high of the eastern part of the field (Section 63) is suggested by only 40 feet of stratigraphic thinning and the most prominent feature of the western area is the small uplift (30 feet of thinning) centered in the northwest part of State Survey 973 and on the adjoining Rachel Ranch lands. The prominent structural trough or low area between the two "highs," as defined by Figures 8 and 9, is only partly, if at all, supported by the data of Figure 10. The local irregularities and closed isopach lines in Sections 56 and 51 (Fig. 10) are due to the effects of faulting, not removed prior to compilation of the data.

Figure 11 is an isopach map of the 4,100-foot sand (Zone A), which is the interval from the top of that sand to the top of the 4,500-foot shale (Zone B), and therefore depicts the structural position of the base of the sand at the time of the close of deposition of the sand. These data support, as on the previous maps, the structurally positive areas on the eastern and western extremities of the field and the structurally low trough between the two "highs." By the inference that the stratigraphic hiatus is equivalent to the uplift sustained, at least 150 feet of upward movement is suggested in the area of Section 63, and approximately 150 feet of uplift is evidenced in the western parts of Sections 46, 47, 48, and the adjoining Rachel Ranch lands on the west. This 4,100-foot sand is postulated to be the near-shore sand deposit of a regressive sea. The excessive thickness of the sand in the trough extending from Section 61 to State Survey 707 may be interpolated from two different views. If the sedimentational or depositional plane is considered at the top of the formation, then the whole of the increased thickness must be interpreted as downwarping during deposition. If a depositional plane is assumed on the base of the formation, then the increased thickness can be inferred as an offshore bar or barrier beach. On the latter assumption, this sand bar, because of its steep easterly

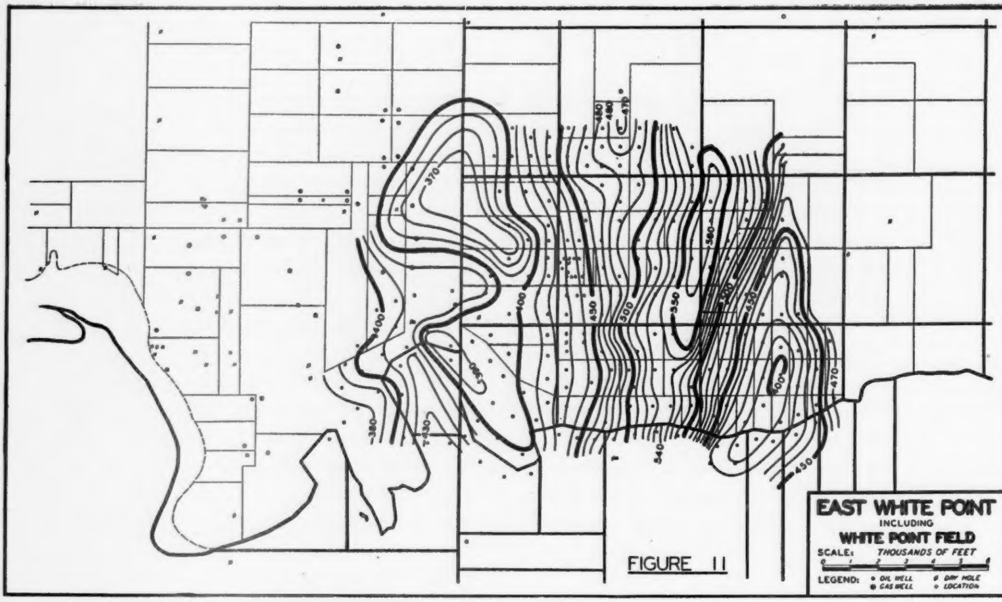

Fig. 11.—Isopach map of 4,100-foot sand (Zone A).

Fig. 12.—Isopach map of 4,500-foot shale (Zone B).

slope, would reflect the shape of either: (a) an offshore bar relevant to an ancient sea on the east; or (b) an elongate sand dune, on an ancient shore, resultant from strong and prevailing westerly winds. Under the assumption that perhaps a or b prevailed, and with a complete knowledge that present conditions might not be criteria or indices of conditions in the geologic past, the writers made a study of the present dunes and bars of the Corpus Christi area. This investigation included examinations of topographic sheets by the United States Geological Survey covering parts of Mustang Island, St. Joseph Island, Padre Island, Live Oak Ridge, Four Bluff Ridge, and other topographic expressions of similar present-day ridge-shaped dunes or bars. The depositional feature of Figure 11, if assumed wholly as a topographic segment, has a maximum elevation or relief of 150 feet in a horizontal distance of approximately 3,000 feet. Offshore bars or continental dunes of the present coast do not display relief of this magnitude. In view of the latter comparison, and by reason of the evidence of partial or complete subsidence suggested and supported by subsequent isopach maps to be presented, the writers propose that the structural trough be considered either (a) the result of local downwarping and the development of an offshore-type bar immediately overlying the subsiding area, or (b) the direct result of localized subsidence (relative uplift of the two positive areas) along the axis of the trough.

Figure 12 is an isopach map of the 4,500-foot shale (Zone B). It illustrates the location and amount of uplift or subsidence in the area during the deposition of these strata. Evidence is presented for the structurally positive segment in the western part of the field, extending from State Survey 973 northeastward to Section 51 and for the structural trough suggested by Figure 11. The positive area centered in Section 63 in the eastern part of the field is only partly substantiated by this interval map. Although the shale has been compacted to approximately 50 per cent of its original depositional thickness, this isopach map demonstrates quiescent conditions, with little continental or structural deformation, over the whole of the area during the period of the shale deposition.

An isopach map, depicting relative uplift during deposition, of the 4,900-foot sand (*Heterostegina* or Greta sand—Zone C) is presented in Figure 13. This map presents data as evidence for: first, a structurally positive area, during deposition, centered in Section 48 and State Survey 707; and second, progressive westward thickening to a negative area on the west or relatively eastward thinning toward a positive area on the east. On the basis of much additional data, not here enumerated, this sand is considered the deposition of a transgressing sea and,

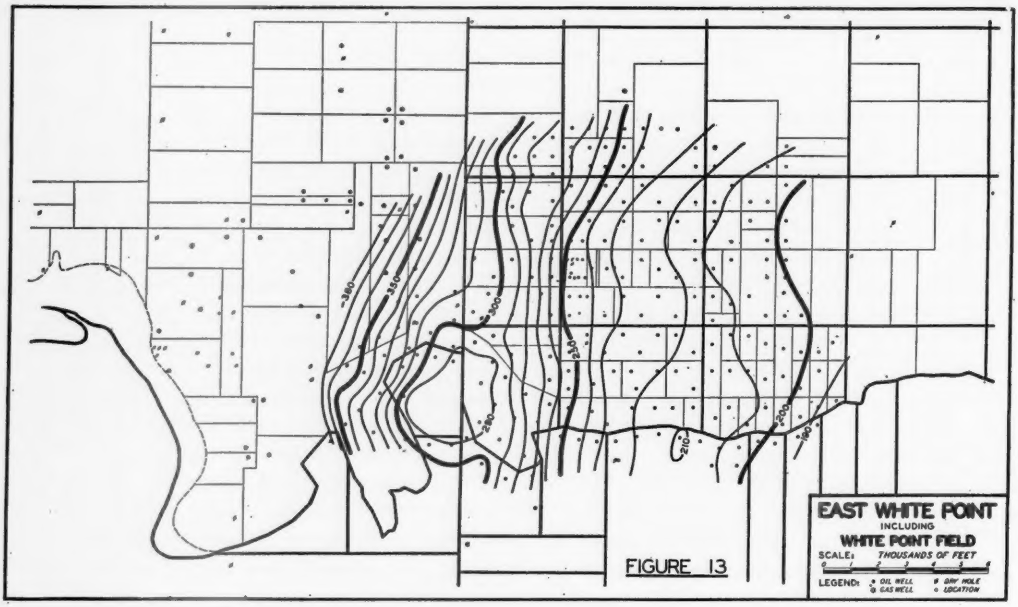

FIG. 13.—Isopach map of 4,900-foot sand (Zone C).

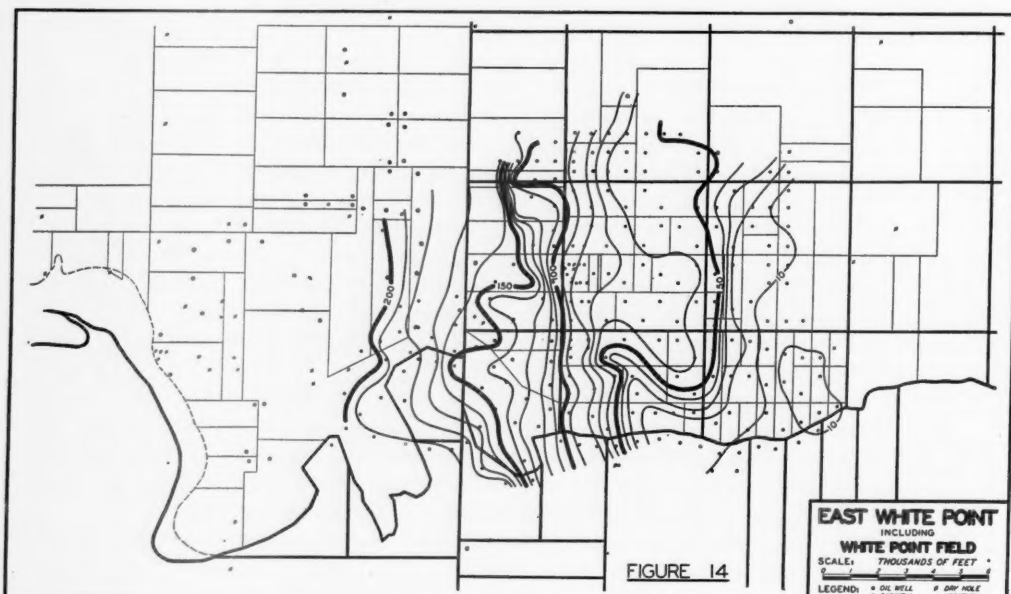

FIG. 14.—Isopach map of 5,300-foot shale (Zone D).

from the data presented on this map, it can be inferred that relative eastward transgression of that sea occurred in this area. It must be borne in mind that the present Gulf of Mexico is southeast of the East White Point field and that the sea regressions and transgressions suggested in this article are considered as relative migrations of the geologically ancient gulf of Mexico. By interpolating from the data of an ancient gulf transgressing from the southeast toward the northwest, and a relative eastward transgression over the East White Point area, it can be shown that an ancestral Nueces river and valley existed west of the present East White Point area. By further deductions, it may be argued that the eastward transgression suggested by Figure 13, as existing in the East White Point producing area, is only a component of the northwestward transgression of the ancient gulf of Mexico into the valley of an ancestral Nueces river and the consequent transgressional deposition on the westward slopes of the downwarping land mass. It may be noted from Figure 13 that the rate of thickening of this zone increases westward from the western parts of Sections 49, 50, and 51. East of this locality, the rate of increase of thickness is approximately 25 feet per mile, and west of this axis the rate of increase is approximately 60 feet per mile. By a close examination of the electrical logs, it can be shown that a sand wedge, within the sand zone, lenses out from west to east at the approximate position of the decrease in rate of thickening. This sand lensing can be interpreted as (a) a depositional unit, or (b) associated with increased thickness of deposition due to isostatic adjustment and compaction of the underlying shale over an older topographic feature. The latter interpretation is here preferred because of the apparent coincidence of the rate-increase in thickening immediately overlying an ancient erosional scar or valley wall (Fig. 15).

Figure 14 is an isopach map of the 5,300-foot shale (Zone D). The effect of faulting and the consequent shortening in interval is suggested by the erratic variations of thickness in Sections 46 and 47, and the localized thin-interval area centering in the eastern part of Section 63 presents an earlier suggestion of the structurally positive area outlined in Figure 11. The outstanding anomaly of Figure 14 is the unusually well developed terraces and curving slopes as designed by the isopach lines. An analysis of these features proved of extreme interest, because, first, no direct association could be shown with the known faults or known structure of the area, and, second, this shale zone proved, by comparison, to have a direct complementary counterpart in the underlying 5,400-foot sand (Zone E). The explanation of this feature is given in the discussion of Figure 15. The reader may note, for comparative

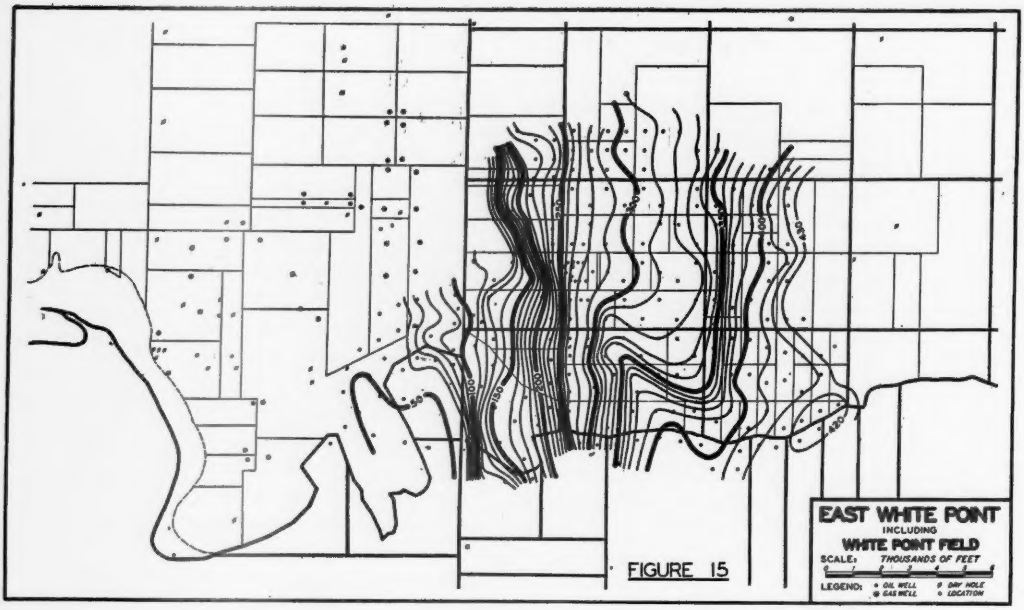

Fig. 15.—Isopach map of 5,400-foot sand (Zone E).

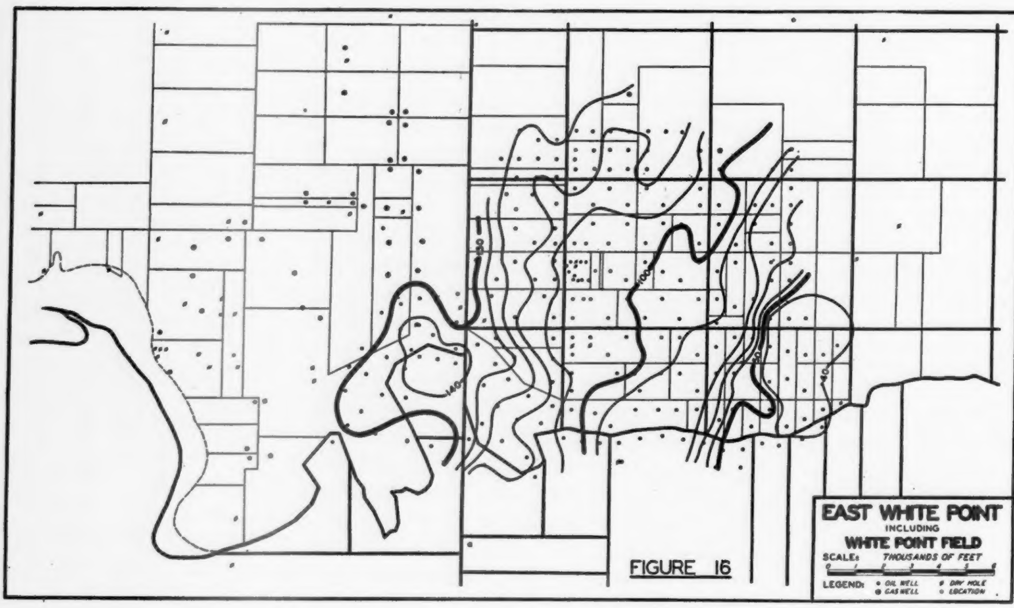

Fig. 16.—Isopach map of 5,500-foot shale (Zone F).

purposes, that this 5,300-foot shale thickens from 10 feet in the eastern part of the field to 200 feet in the western productive area.

An isopach map of the 5,400-foot sand (Zone E) is shown in Figure 15. A positive area of minor importance is suggested by the localized thin area in Section 63 and State Surveys 748-A and 748-B on the southeast side of the field. Of primary importance is the fact that this sand zone thins westward from a maximum of 430 feet in Section 62 to a minimum of 50 feet in the area of State Survey 973. When considered with a depositional plane at the base of the sand, this thickness map of the 5,400-foot sand, with its terraces, slopes, and meander scarps, displays the typical features of degradation and planation common to the erosional cycle of a normal river in an area being subjected to periodic uplift and rejuvenation. The terraces and slopes, suggested by the map, can not be associated with known faults or structure, and, by contrast, the isopach map shown in Figure 14 reflects the effects of unequal deposition of the overlying shale on an older erosional topography. Three periods of uplift, and consequent erosion by an ancestral Nueces river, are suggested by the reconstructed terraces and incident slopes. By a detailed study of the isopach maps of the 5,300-foot shale (Zone D—Fig. 14) and the 5,400-foot sand (Zone E—Fig. 15), the writers propose the following geological history of these stratigraphic units.

1. Deposition of the 5,400-foot sand (Zone E) over the whole area to a thickness of 450–500 feet.
2. Continental uplift of the whole area following deposition of the sand, concurrent with regression of the ancient gulf of Mexico and emergence of the land mass.
3. Development of stream drainage and stream erosion of the land mass by an ancestral Nueces river.
4. Cyclic upward movement of the land mass with its consequent erosion. Three, or more, stages or periods of uplift and erosion are propounded on the basis of the reconstructed terraces and slopes.
5. Continental subsidence of the land mass following erosion, concurrent with transgression of the ancient gulf of Mexico and submergence of the land mass.
6. A depositional lagoonal-type filling of the old topography with the shale as an unconsolidated mud.
7. Subsequent compaction of the shale.

Figure 16 presents an isopach map of the 5,500-foot shale (Zone F). Evidences of uplift, concentric with uplifts suggested by previous maps, are noted in Section 63 and in the northern part of State Survey 973. This shale interval thickens progressively northwest, indicative of

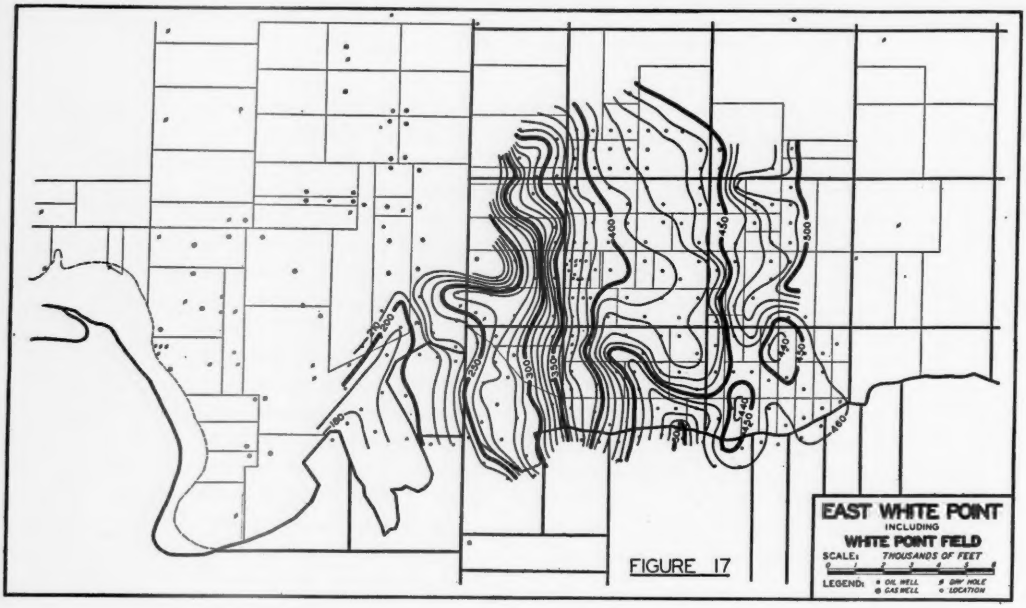

FIG. 17.—Isopach map of combined 5,400-foot sand and 5,500-foot shale (zones E and F).

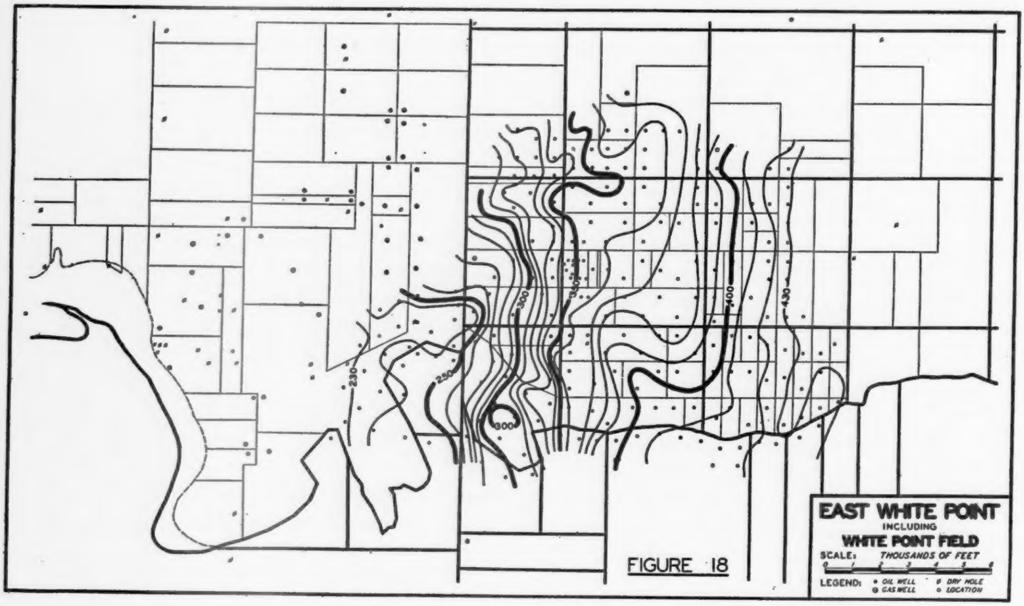

FIG. 18.—Isopach map of combined 5,300-foot shale and 5,400-foot sand (zones D and E).

continental downwarping or tilting in that direction during deposition. Minor fault irregularities are reflected by the erratic thicknesses in the vicinity of Sections 46 and 51 on this map.

It has been suggested by some that the terraces and slopes on the 5,300-foot shale (Zone D) and on the 5,400-foot sand (Zone E) might be the result of sand and shale lensing at the top or base of these strata. For the purpose of discrediting the possibility of such irregularities due to lensing, several maps have been prepared showing isopach intervals of various combinations of strata.

Figure 17 is an isopach map of the interval from the top of the 5,400-foot sand to the top of the 5,600-foot sand (zones E and F). Additional substantive data are: first, the well developed erosional terraces and slopes in their exact previous locations, although their magnitudes have been modified by the northwestward thickening of the 5,500-foot shale (Zone F); and, second, the structurally positive area centered in Section 63. This isopach map is considered as confirmatory evidence to the erosional unconformity.

Figure 18 is an isopach map of the interval from the top of the 5,300-foot shale to the top of the 5,500-foot shale (zones D and E). This map similarly depicts the erosional unconformity and topography, although the steepness of the slopes and the magnitude of the relief have been partly obscured by the shale filling. The inherent topographic features suggested by this map are the net results of the isostatic adjustments and compaction of the 5,300-foot shale, following deposition of the shale and the subsequent overburdening of that unconsolidated material. Faulting is suggested by the unusual isopach intervals in Sections 46, 47, and 51, and localized uplift, during period of deposition, can be inferred in the vicinity of Section 63.

Figure 19 is an isopach map of the interval from the top of the 4,900-foot sand to the top of the 5,500-foot shale (zones C, D, and E). By the close of deposition of the 4,900-foot sand, two positive areas were beginning to develop and the erosional topography of the 5,400-foot sand (Zone E—Fig. 15) had been almost, if not entirely, obscured by sedimentation and the structural anomalies. The two positive areas suggested by this map, are concentric with previous and subsequent uplifts, being located, respectively, in the southern part of Section 63 and in the northern part of State Survey 973. The effects of faulted intervals are reflected by the closed isopach lines near the northeast corner of Section 47.

Figure 20 is an unadjusted isopach map of the interval from the top of the 5,300-foot shale to the top of the 5,600-foot sand (zones D, E, and F), and illustrates the exceptional effects of faulting on the isopach

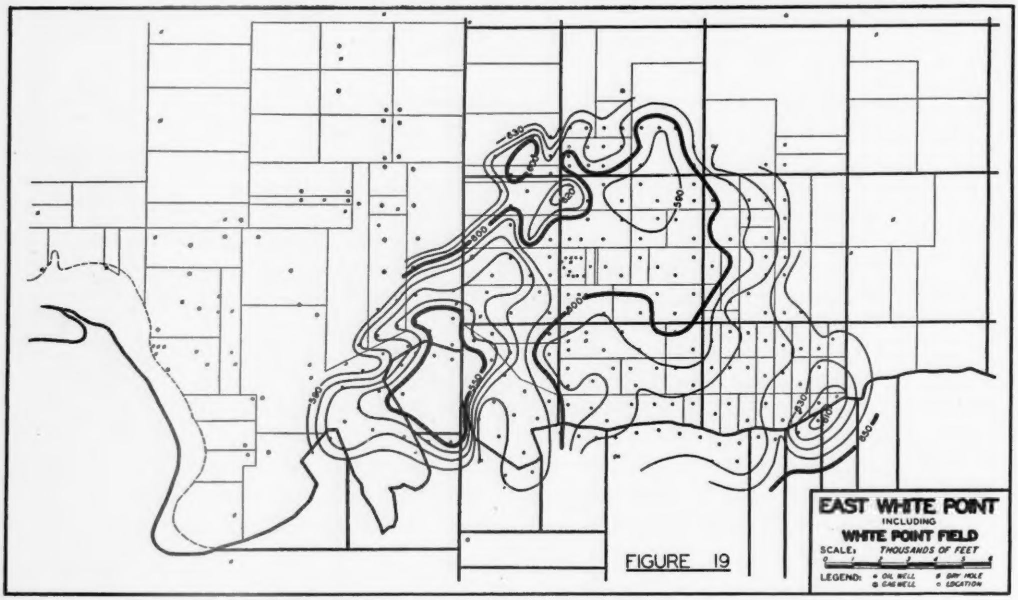

FIG. 19.—Isopach map of interval from top of 4,900-foot sand to top of 5,500-foot shale (zones C, D, and E).

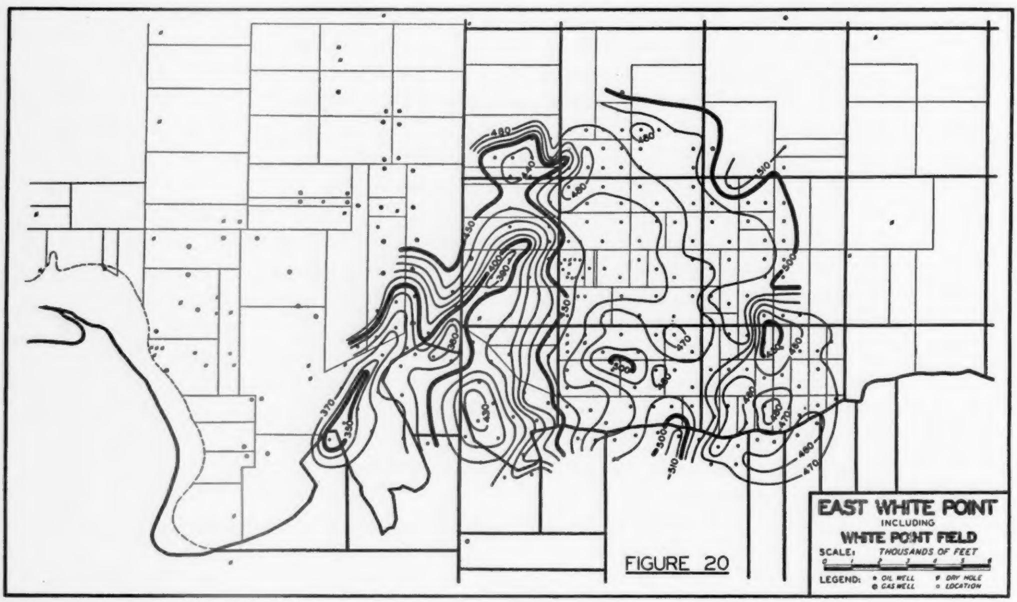

FIG. 20.—Isopach map of interval from top of 5,300-foot shale to base of 5,500-foot shale (zones D, E, and F).

intervals, unless such intervals are properly compensated. The faults strike northeast and southwest, and extend from the northern part of State Surveys 974 and 975 northeastward to Sections 46 and 51. It may be noted, by a comparison with Figure 15, that the strike of the faults is transverse to the alignment and trend of the slopes and terraces of the erosional unconformity. Further evidence of the erosional unconformity suggested by Figure 15 may be noted by a study of the many fault displacements at the erosional break. Most of the faults in the East White Point field, known to date, are wholly or partly pre-5,400-foot sand erosion, or pre-5,300-foot shale deposition in age, and are encompassed in strata below the stratigraphic hiatus. In many cases, the complete displacement and throw of the fault are obliterated and erased by the erosional period, while those faults extending above the unconformity have a decreasingly less amount of throw at points immediately above the erosional stratigraphic break.

For a more visual presentation of the erosional unconformity on the top of the 5,400-foot sand (Zone E) and to illustrate the complementary filling of that erosional topography by the deposition of the 5,300-foot shale (Zone D), perspective isometric block diagrams have been prepared of a segment of the producing area of the East White Point field. Figure 21 presents the area of the field selected as the segment used in the preparation of the block diagrams of Figures 22 and 23. Two isometric views, one looking southeast and one looking northeast, are shown of the 5,400-foot sand and the overlying 5,300-foot shale, and the reader may better visualize the data by the conception of being placed west of the mass and observing the blocks as isometrically distorted diagrams illustrative of the topographic relief suggested by the profile views of the north, south, and west sides of the two formational strata. In each case, a depositional datum has been selected at the base of the 5,400-foot sand (Zone E) and at the top of the 5,300-foot shale (Zone D). In this manner, the top of the 5,300-foot shale and the base of the 5,400-foot sand are presented as horizontal planes.

Figure 22 presents isometric block diagrams, as viewed from the southwest and northwest, of the 5,300-foot shale (Zone D) and the 5,400-foot sand (Zone E). These block diagrams have been prepared from the isopach maps presented in Figures 14 and 15. As so presented, the 5,400-foot sand is pictured as post-deposition and post-erosion, while the 5,300-foot shale is depicted as post-deposition and post-compaction. It may be noted that the overlying shale is complementary to every erosional feature of the 5,400-foot sand lying beneath it with the one exception that, by reason of compaction, subse-

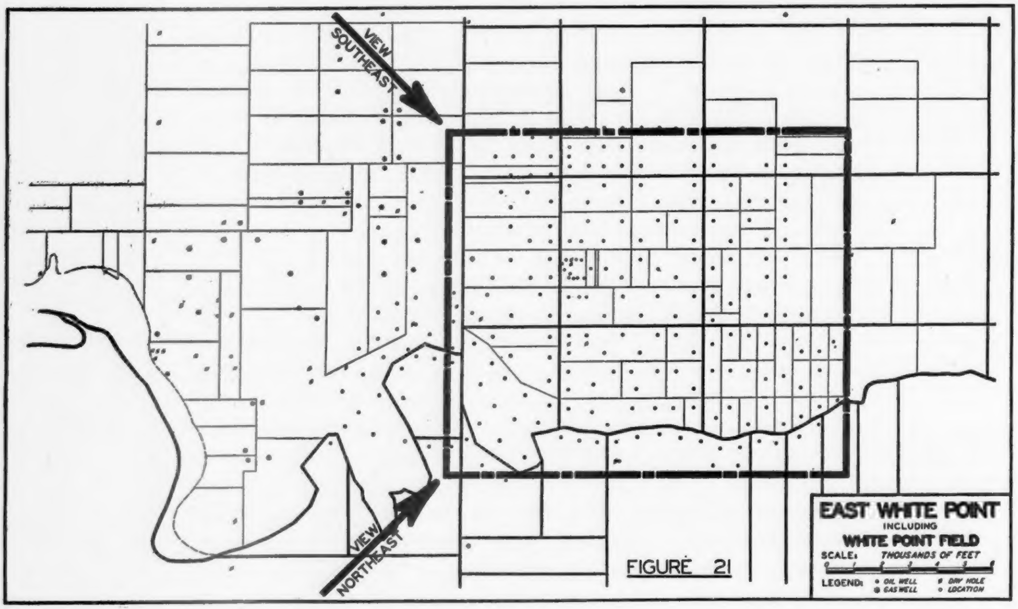

FIG. 21.—Map of East White Point field showing area of isometric perspective block diagrams of Figures 22, 23, 24, 25, 26, 27, 28, 29, and 30.

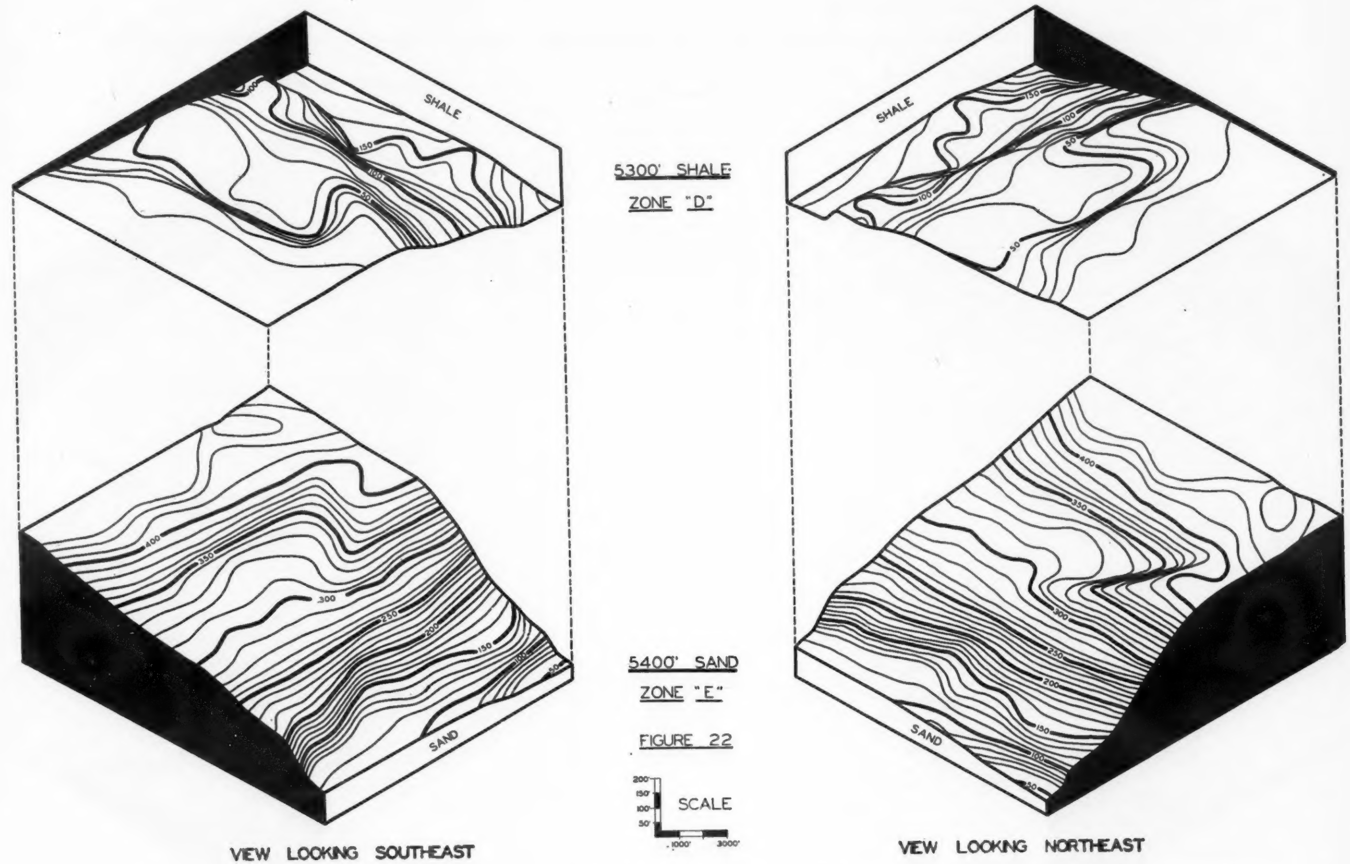

FIG. 22.—Isometric perspective block diagrams of 5,300-foot shale and 5,400-foot sand, post-deposition, post-erosion and post-compaction.

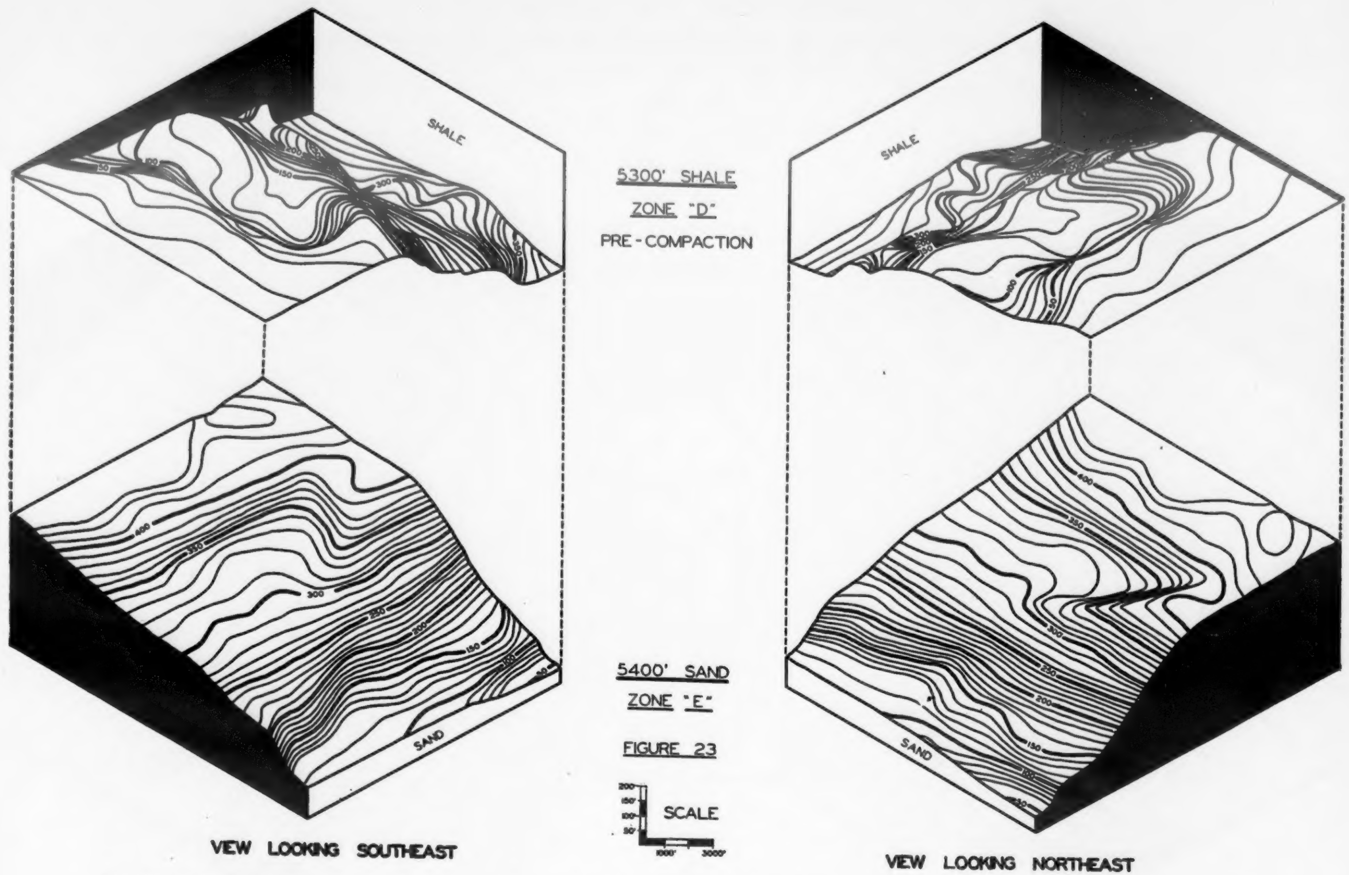

FIG. 23.—Isometric perspective block diagrams of 5,300-foot shale and 5,400-foot sand, post-deposition, post-erosion, and pre-compaction.

quent to deposition and loading, the present volume of the shale mass is insufficient to effect a conformable relationship between the depositional planes at the base of the sand and the top of the shale mass. As previously shown by Figure 18, this disconformity may be noted by the isopach map of the combined 5,300-foot shale–5,400-foot sand zones. Athy[15] has shown "that the compressibility of sediments has been an important factor in developing structure . . . but very little has been done to establish, by positive evidence, its relative importance."[16] Although the data were obtained from samples from northern Oklahoma, Athy[17] has shown, by his compaction-depth curve of samples of shale from northern Oklahoma, that shales buried to a depth of 5,300-feet have been affected by a compaction of approximately 46 per cent. By the trial-and-error method, the writers have determined that a compaction of approximately 52–54 per cent has been sustained by the 5,300-foot shale (Zone D) of the East White Point field. This amount of compaction is required to afford, by expansion of the shale to its original thickness, a complete parallelism and conformity of the depositional plane at the top of the shale with the datum plane at the base of the 5,400-foot sand. If, due to continental tilt and differential movement of respective parts of the East White Point field area, a slight discordance exists between these two datum planes, then a compaction of only 45–50 per cent is required to fulfill the requisites of the filling to base level of the erosional topography.

Figure 23 is a graphic picture, by block diagrams, of the shale in its pre-compacted condition. The isometric block diagrams of the 5,400-foot sand of Figure 23 are the same as those previously shown on Figure 22, and have been compiled from the isopach map of Figure 15. The 5,300-foot shale as shown on Figure 23, however, represents the pre-compaction thickness of this formation at the close of deposition of that stratum. For the purpose of this diagrammatic sketch, a compaction of 50 per cent was assumed; hence, the thickness of this shale is shown as double that of Figure 22. By the allowance of this percentage of compaction, it may be readily noted that approximate conformity of sedimentation and deposition planes existed as between the top of the 5,300-foot shale and the base of the 5,400-foot sand at the close of deposition of the shale filling. In Figures 22 and 23, no compaction of the 5,400-foot sand (Zone E) has been assumed, and the isometric perspective block diagrams of that stratum are drawn true to scale.

[15] L. F. Athy, "Density, Porosity, and Compaction of Sedimentary Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 1 (January, 1930).

[16] *Ibid.*, p. 1.

[17] *Ibid.*, p. 9, Fig. 4.

Figures 24, 25, 26, 27, 28, 29, and 30 present a group of generalized isometric perspective block diagrams and depict, in proper geologic and chronologic order, the various stages in the deposition of the strata in the East White Point field from the top of the 4,100-foot sand to the top of the 5,600-foot sand (zones A, B, C, D, E, and F) as previously discussed. The area included in the block diagrams is the same area as that shown on Figure 21. The reader views the diagrams, in perspective, as if looking northeast from the southwest corner of the block. The writers have drawn freely from the data presented by

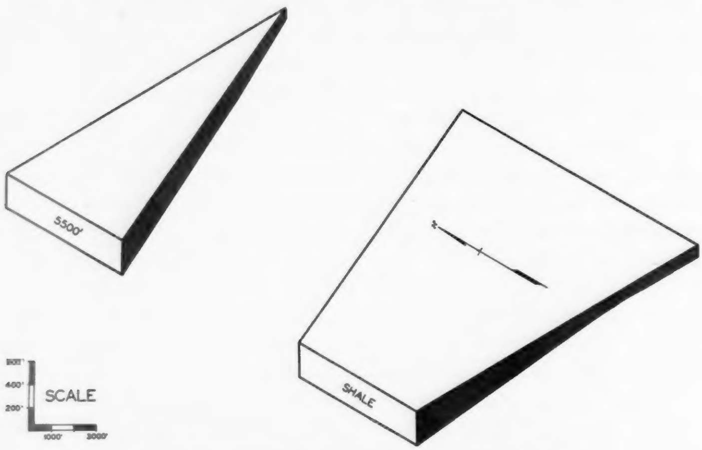

FIG. 24.—Isometric perspective block diagram of East White Point area after deposition of 5,500-foot shale (Zone F).

Athy[18] in his compaction-depth curve, and desire to acknowledge the usefulness of that curve in estimating the respective compaction percentages of shale with varying amounts of overburden. In every case, except at the erosional unconformity on the top of the 5,400-foot sand (Zone E), the close of deposition of each stratum has been considered a horizontal plane at base level, and variations in thickness and interval have been interpreted as the normal result of isostatic adjustments or continental tilt.

Figure 24 presents the first stage in the deposition of the strata discussed in this study, and is descriptive of the close of deposition of the 5,500-foot shale (Zone F). This shale interval is shown as expanded from its present thickness (Fig. 16) to the approximate pre-compaction thickness at the close of deposition.

[18] L. F. Athy, *op. cit.*, p. 4, Fig. 4.

Figure 25 presents the second stage in the deposition of some of the Oligocene strata, and illustrates the conditions obtaining at the close of the 5,400-foot sand (Zone E). This sand interval, on the basis of many additional data not incorporated in this paper, is assumed to have been deposited to an average thickness of approximately 450–500 feet over the whole of the area of the East White Point field. By reason of the overburden due to the deposition of the 5,400-foot sand, 15 per cent compaction has been computed on the 5,500-foot shale, and the vertical section of the shale is reduced accordingly in Figure 25.

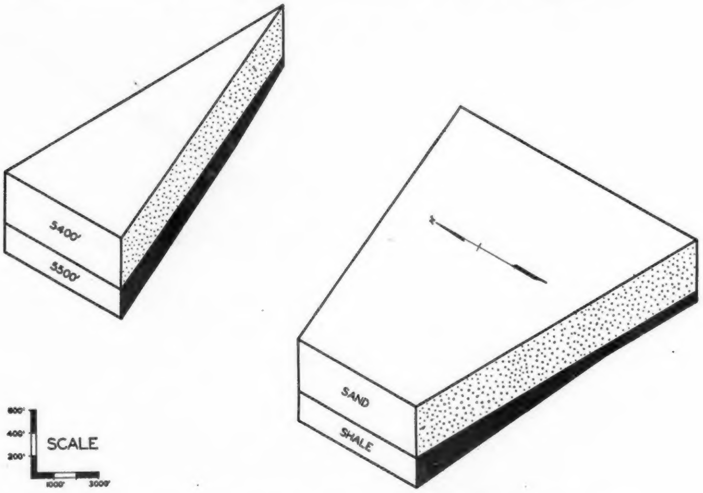

FIG. 25.—Isometric perspective block diagram of East White Point area after deposition of 5,400-foot sand (Zone E).

Figure 26 presents the third stage in the deposition, and shows the area at the close of the erosional period following emergence of the land at the close of the 5,400-foot sand deposition. In this diagram, no expansion of the 5,500-foot shale has been inferred by reason of the lessening of the overburden.

The fourth stage in the depositional cycle of the area is shown in Figure 27, which illustrates the conditions as existing at the close of deposition of the 5,300-foot shale (Zone D). This 5,300-foot shale zone has been expanded from its present compacted thickness to the interval existent at the close of deposition and in its unconsolidated condition. Again it is called to the reader's attention that this shale interval completely obscures, by filling, the erosional topography on the top of

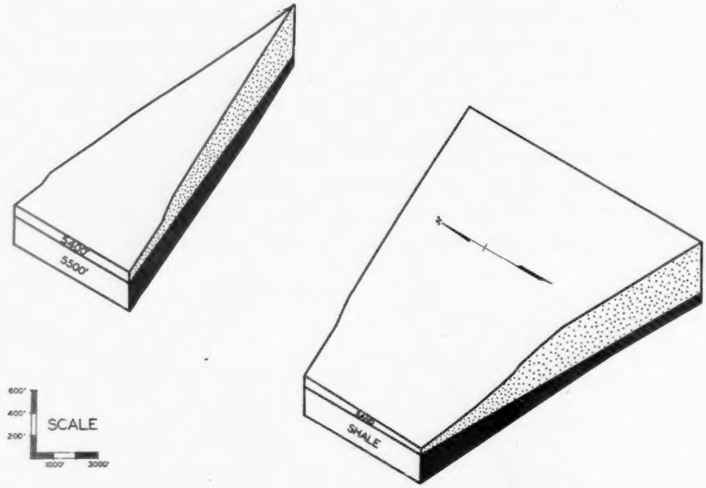

FIG. 26.—Isometric perspective block diagram of East White Point area after erosion of 5,400-foot sand (Zone E).

the 5,400-foot sand. No additional compactional adjustments have been made in the thickness of the 5,500-foot shale on this diagram since the overburden as shown approximates that of Figure 25.

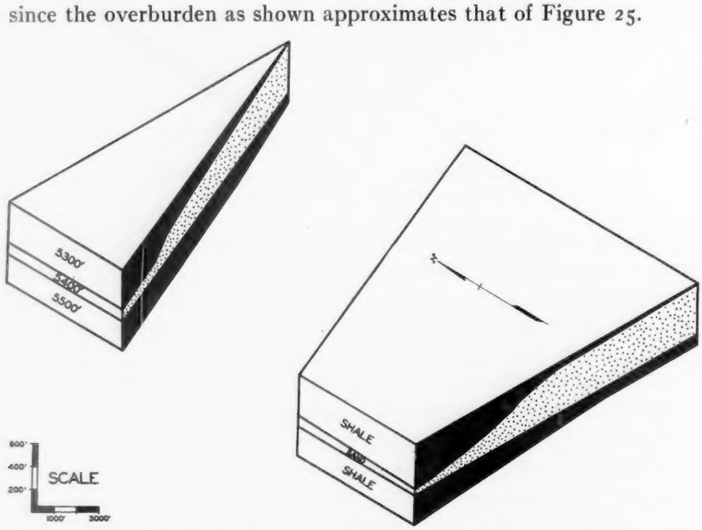

FIG. 27.—Isometric perspective block diagram of East White Point area after deposition of 5,300-foot shale (Zone D).

Figure 28 presents the fifth stage in the depositional history of the area, and delineates the existing conditions at the close of deposition of the 4,900-foot sand (Zone C). This stage, in the geologic history of the East White Point field, marks the beginning of the development of the compaction terraces and slopes on and within the 5,300-foot shale stratum (Fig. 14). Because of the increased overburden or loading of sediments, the total compaction computed on the 5,300-foot shale and the 5,500-foot shale on this diagram are 10 per cent and 20 per cent, respectively.

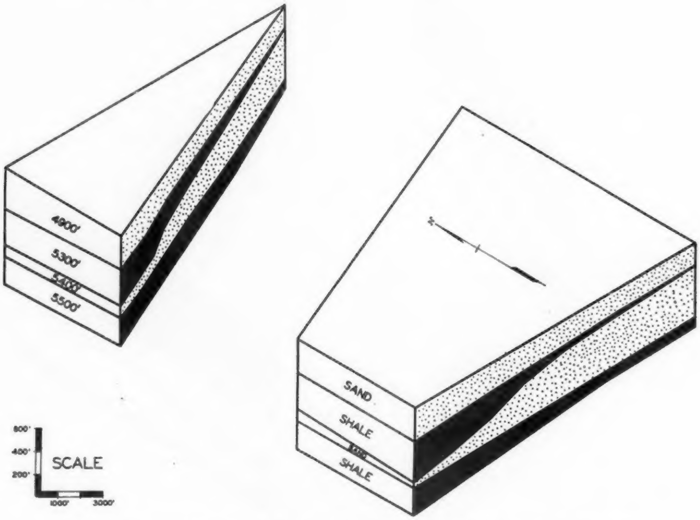

FIG. 28.—Isometric perspective block diagram of East White Point area after deposition of 4,900-foot sand (Zone C).

Figure 29 presents the sixth stage in this chronological history of depositional events, and is the interpretation of conditions existing at the close of the 4,500-foot shale deposition (Zone B). Total compactions, subsequent to deposition, of 25 per cent and 30 per cent, respectively, have been computed on the 5,300-foot shale (Zone D) and the 5,500-foot shale (Zone F) of this diagram. This increase in compaction of the 5,300-foot shale has accentuated the formation of the compaction slopes and terraces of that formation.

Figure 30 presents the depositional, and perhaps structural, conditions in the area at the close of the 4,100-foot sand (Zone A) deposition. This 4,100-foot sand has been shown, in previous discussion with-

in this paper, as the deposit of a regressive sea, and the possibility of a topographic dune or bar anomaly to account for the local elongate area of increased deposition has been previously discussed with reference to Figure 11. Compactions to the total amount of 15 per cent, 30 per cent, and 35 per cent have been computed on the 4,500-foot shale, the 5,300-foot shale, and the 5,500-foot shale, respectively, on this isometric block diagram.

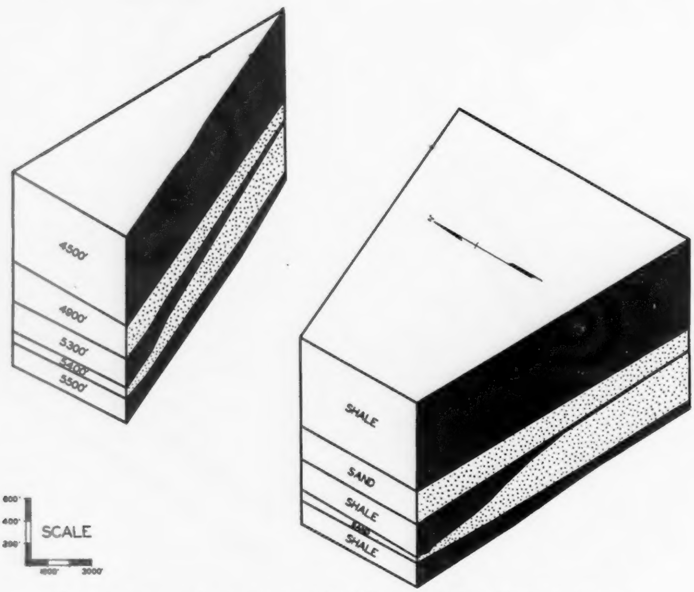

FIG. 29.—Isometric perspective block diagram of East White Point area after deposition of 4,500-foot shale (Zone B).

GEOLOGICAL CORRELATIONS

In the preceding paragraphs, an effort has been made to visualize some of the more important factors of deposition, stratigraphy, and structure of certain strata of the Oligocene age in the East White Point field. A comparison of the older geologic column of the Oligocene with the present nomenclature, incorporating, in chronologic order, the principal subdivisions of those strata as made in the intervening years is presented in Figure 31.

As early as 1924, Deussen[19] suggested the Oligocene of the Coastal

[19] Alexander Deussen, "Geology of the Coastal Plain of Texas West of the Brazos River," *U. S. Geol. Survey Prof. Paper 126* (1924), p. 21.

Plain of Texas as lying conformably on the Eocene and unconformably below the Miocene. In Deussen's[20] subdivision, the Catahoula sandstone formation was grouped in the Oligocene, while the Frio formation, lying beneath the Catahoula, was indicated as a deposit of either late Eocene or early Oligocene age. This alternative age is shown by the interpretation of column 1 in Figure 31.

In 1926, Bailey[21] resubdivided and renamed the Oligocene strata of

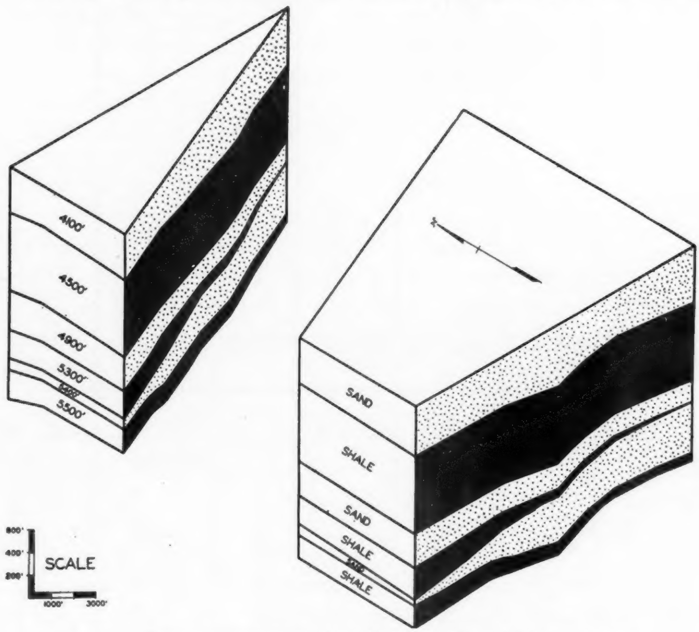

FIG. 30.—Isometric perspective block diagram of East White Point area after deposition of 4,100-foot sand (Zone A).

Southwest Texas and suggested an unconformity at the base of this series. At that time, the beds formerly called Catahoula were renamed the Gueydan formation, and the formation was further subdivided into three members,[22] namely, the Fant Tuff member or lower Gueydan; the Soledad volcanic conglomerate, sandstone, and tuff or middle Gueydan; and the Chusa argillaceous tuff and tuffaceous clay or upper

[20] *Ibid.*, pp. 21 and 92.

[21] Thomas L. Bailey, "The Gueydan, a New Middle Tertiary Formation from the Southwestern Gulf Coastal Plain of Texas," *Univ. Texas Bull. 2645* (December, 1926).

[22] *Ibid.*, p. 65.

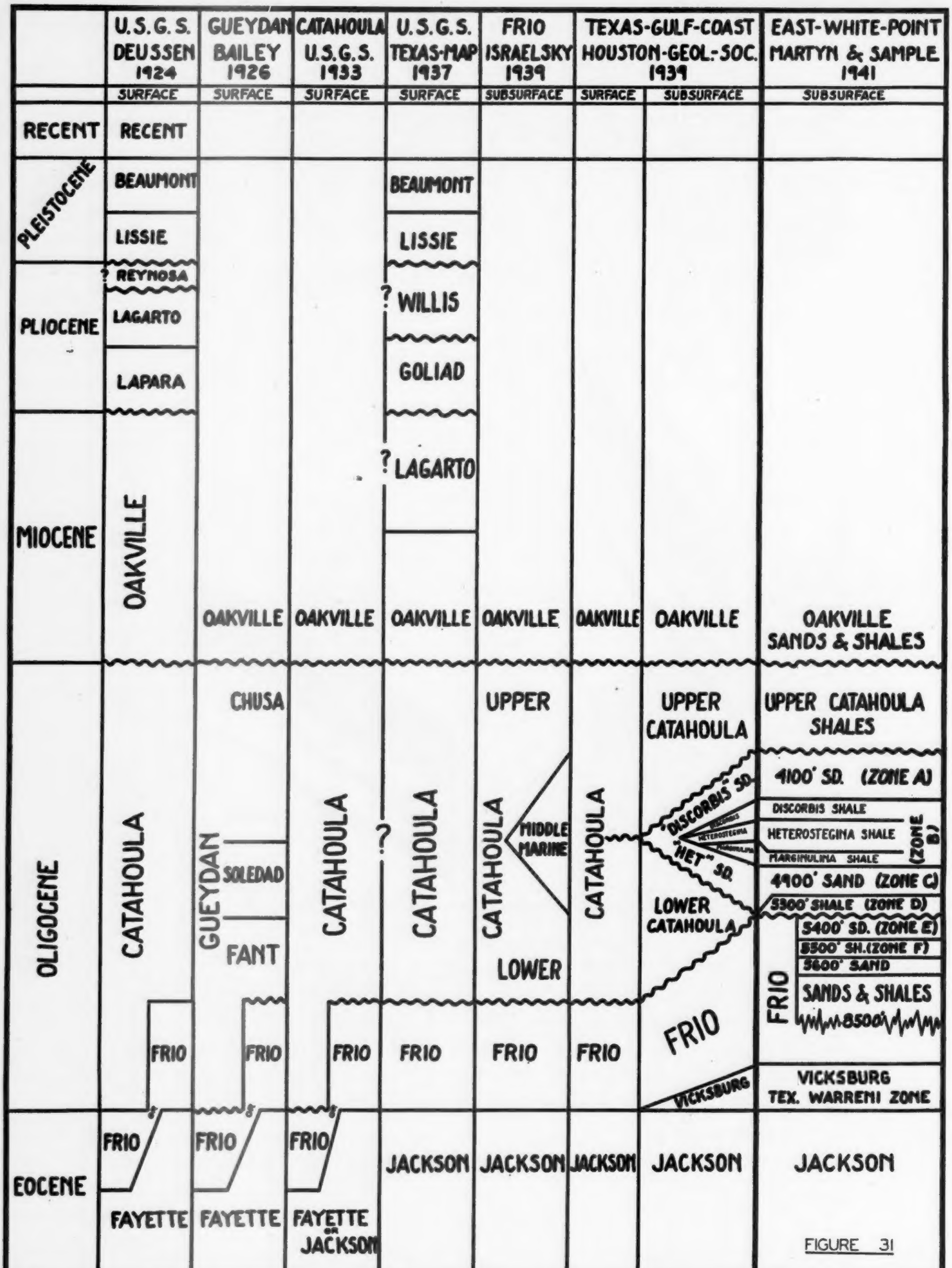

FIG. 31.—Geologic correlation chart of Oligocene strata of East White Point field.

Gueydan. Bailey[23] placed a somewhat different interpretation on the "Frio formation" than that in usage by any previous writer. In Bailey's definition, the Frio formation was restricted to designate the argillaceous beds lying conformably on the Fayette and possibly unconformably beneath the Gueydan, and comprising strata probably of Eocene age. Bailey's[24] subdivision of the Oligocene strata is presented in column 2 of Figure 31, and the alternate Eocene or Oligocene age of the Frio is also indicated.

Following the proposal in 1932 by Gardner and Trowbridge[25] to substitute the name Yeager for the beds assigned to the Frio by Bailey[26] and to use the name Frio for the volcanic series designated by Bailey as the Gueydan, a committee,[27] acting under the sponsorship of the San Antonio Geological Society, opposed the substitution of the name Yeager clay for the Frio clay, and recommended that either the name Catahoula or Gueydan be delegated to the formation termed Gueydan by Bailey. At the conclusion of correspondence between this committee and the acting director of the United States Geological Society, reported by Lahee,[28] the decision was reached to use "Catahoula tuff" for Bailey's "Gueydan" and to retain the name "Frio clay" for the formation between the Fayette sandstone below and the Catahoula tuff above. Bailey[29] later accepted the nomenclature as suggested by the Geological Survey. In order to show this readjustment of formational names, the Oligocene nomenclature, as of early 1933, is shown in column 3 of Figure 31. Gardner and Trowbridge[30] suggested the possibility of either Oligocene or Eocene age for the Frio clay equivalents, and this alternative stratigraphic position has been so indicated in the 1933 nomenclature chart (Fig. 31).

The columnar geologic section and subdivisions of the Oligocene series, as shown by the geologic map of the state of Texas issued in 1937, are shown in column 4 of Figure 31. On this map, the Frio was

[23] *Ibid.*, p. 44.

[24] *Ibid.*, p. 36.

[25] Julia Gardner and A. C. Trowbridge, "Yeager Clay, South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 4 (April, 1931), p. 470.

[26] Thomas L. Bailey, *op. cit.*

[27] E. H. Finch, Phil F. Martyn, Olin G. Bell, and R. F. Schoolfield, "Yeager Clay, South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 8 (August, 1931), pp. 967–70.

[28] F. H. Lahee, "Frio Clay, South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 1 (January, 1932), pp. 101–02.

[29] Thomas L. Bailey, "Frio Clay, South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 3 (March, 1932), pp. 259–60.

[30] Julia Gardner and A. C. Trowbridge, *op. cit.*, p. 470.

grouped in the Oligocene, and the questionable Miocene-Oligocene age of the Catahoula was indicated.

In a report of a study group of the Houston Geological Society during 1939, under the leadership of Israelsky,[31] some doubt was shown as to the exact subsurface correlation of the Frio. Subdivisional units of the Catahoula in the subsurface were suggested by Israelsky in that paper as follows.

> For convenience we may, when the "Middle Marine Oligocene" is present, use the names Upper Catahoula, "Middle Marine Oligocene," or "Marine Catahoula," and Lower Catahoula, bearing in mind the Upper and Lower Catahoula will vary according to the development of the "Middle Marine Oligocene" or "Marine Catahoula." Where the Marine phase is poorly developed (updip) we simply recognize Catahoula (undifferentiated).[32]

It has been shown by Israelsky[33] that subsurface correlations of beds equivalent to the Soledad of Bailey[34] can be made with strata extending into the subsurface below the "Middle Marine Oligocene" or "Marine Catahoula." The subdivisions of the Oligocene as suggested by Israelsky[35] are shown in column 5 of Figure 31.

A similar Houston Geological Society study group committee[36] working on the subsurface stratigraphic problems of the Oligocene, and particularly with respect to the "Middle Oligocene" stratigraphic wedge, proposed the correlations between surface and subsurface Oligocene strata as shown by column 6 of Figure 31. The findings of this study group were unpublished, but were presented, in data form, before the group meetings of the Houston Geological Society and the South Texas Geological Society. On the basis of stratigraphic sedimentary units, the Frio was carried into the subsurface, below an unconformity, to merge in the extreme downdip section with beds of the lower part of the "Marine Oligocene" wedge. This "Marine Oligocene" wedge was proposed by the committee to constitute the complete cycle of sedimentation of transgressive-regressive seas and separated, by unconformities, from the beds above it and beneath it. A further subdivision of the "Middle Oligocene" wedge was suggested: the upper sand deposit of the wedge, deposited by the regressing sea, would be

[31] M. C. Israelsky, "Notes on the Frio," Report of Houston Geological Society Study Group, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 2 (February, 1940), pp. 376–82.

[32] M. C. Israelsky, *op. cit.*, Vol. 24, No. 2 (February, 1940), pp. 381–82.

[33] M. C. Israelsky, personal communication.

[34] Thomas L. Bailey, *op. cit.*

[35] M. C. Israelsky, *op. cit.*, Vol. 24, No. 2 (February, 1940).

[36] A. P. Allison, Lon. D. Cartwright, Morgan J. Davis, Carl B. Richardson, Richard D. White, J. W. Kisling, Jr., and Phil F. Martyn.

termed the "*Discorbis* sand"; the lower sand of the marine wedge, deposited by the transgressing sea, would be named the "*Heterostegina* sand"; and the shale interval between the two sands would be known by their faunal names of "*Discorbis*," "*Heterostegina*," and "*Marginulina*" shales, respectively. The Frio of the surface was carried into the subsurface, by correlation, and was thought, by the committee, to be the approximate depositional equivalent of large sand bodies downdip called Vicksburg. Other subsurface correlations of divisional units of the Catahoula were found to agree, essentially, with the nomenclature suggested by Israelsky[37] in his classifications of "Upper Catahoula" and "Lower Catahoula."

The subdivisions of the stratigraphy of the East White Point field, as suggested by the writers of this paper, are shown in column 7 of Figure 31. It can be readily noted that the following correlations exist.

1. The 4,100-foot sand (Zone A) of the East White Point area is regarded to be the equivalent to the "*Discorbis* sand," and the unconformity shown at the top of this sand has been discussed in previous paragraphs of this paper.

2. The 4,500-foot shale (Zone B) of the East White Point field is considered the equivalent of the combined "*Discorbis*," "*Heterostegina*," and "*Marginulina*" shales, and can be shown, by faunal content, to be an identical paleontological unit.

3. The 4,900-foot sand (Zone C) of the East White Point field is considered as synonymous with the "*Heterostegina* sand," the deposit of a transgressing sea and the basal member of the "Middle Oligocene" wedge.

4. The 5,300-foot shale (Zone D) is tentatively placed by the writers, as a correspondent bed to the lower Catahoula, but correlation will permit, on the basis of its position above the erosional unconformity, its classification with strata of the "Middle Oligocene."

5. The 5,400-foot sand (Zone E) and the 5,500-foot shale (Zone F) of the East White Point area are adjudged by the writers, because of their position below the erosional unconformity, to be the top members, in this area, of the Frio formation. Deeper wells of the East White Point field have penetrated alternating sands and shales of the Frio to the maximum depth of 8,483 feet.

SUMMARY AND CONCLUSIONS

From the factual and correlative data presented in the foregoing paragraphs, the writers propose the following geological conclusions.

[37] M. C. Israelsky, *op. cit.*, Vol. 24, No. 2, pp. 381–82.

1. A negative area receiving sedimentary deposits, comprising an ancestral gulf of Mexico, is suggested in the general East White Point area of South Texas during Oligocene time.

2. Relatively shallow-water deposition occurred in the East White Point area during Frio time, as evidenced by the alternating sand and shale beds of that formation.

3. Continental uplift or relative regression of water in the ancient gulf of Mexico occurred in the East White Point area at the close of deposition of the 5,400-foot sand (Zone E), as manifested by the erosional unconformity at the top of that sand horizon. (So far as is known by the writers, this is the first time that an erosional unconformity, based on subsurface data, alone, has been suggested in the subsurface of the Texas Gulf Coast.)

4. An ancestral Nueces river, Nueces bay, or both, was located west or southwest of the East White Point field area during the period of erosion of the 5,400-foot sand (Zone E). This ancestral Nueces river, and possibly Nueces bay, is supported by the data of the erosional meander scarp topography and the apparent relative westward recession of that ancient river with the recurrent uplifts occurring post-5,400-foot sand deposition.

5. The erosional unconformity here proposed, because of the geologic time break recorded, marks the top of the Frio formation. Inasmuch as the unconformity at the top of the Frio merges with the unconformity at the base of the "Middle Oligocene" wedge at some position in the downdip subsurface, such a merging being at or adjacent to the point of maximum retreat of the ancient gulf of Mexico in that respective depositional cycle, it is considered probable that the erosional unconformity depicted on the top of the 5,400-foot sand is the equivalent of two unconformities.

6. Cyclic rejuvenations or uplift of the land mass occurred at various time intervals after deposition of the 5,400-foot sand. These periodic uplifts are indicated by the development of terraces at various levels and are the normal result of degradation and planation in an area being subjected to recurring uplift. Three such periods of uplift and subsequent quiescence are suggested by the reconstructed terraces and slopes.

7. The location of the ancient gulf of Mexico was some distance removed from the present location of the East White Point field at some geologic time post-deposition of the 5,400-foot sand and pre-5,300-foot shale deposition. This geologic feature is suggested by the more than 400 feet of topographic relief demonstrated by the erosional topography of the 5,400-foot sand.

8. Submergence of the land mass or relative transgression of the ancient gulf of Mexico occurred, in the East White Point area, post-erosion of the 5,400-foot sand or pre-deposition of the 4,900-foot sand. This fact is supported by the 5,300-foot shale filling of the eroded topography and by the wedge of marine Oligocene sediments overlying the unconformity. It is the thought of the writers that the 5,300-foot shale is of lagoonal-type deposition, the result of drowning of the ancestral Nueces river valley, and its filling behind barrier beaches or bars.

9. Continental uplift or relative regression of the ancient gulf of Mexico occurred in the East White Point area at the close of deposition of the 4,100-foot sand. This recession of the sea is suggested by the possible interpretation of an elongate offshore bar or sand dune as suggested in the isopach map of the 4,100-foot sand presented in Figure 11.

10. Two structurally positive areas and one structurally low or trough area were present in the East White Point field area during the periods of deposition of the Oligocene strata now grouped between the top of the 4,100-foot sand and the base of the 5,500-foot shale. These positive and negative areas are substantiated by the isopach maps of the respective strata presented in Figures 11, 12, 13, 14, 15, and 16.

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VOL. 25, NO. 11 (NOVEMBER, 1941), PP. 2010-2020, 7 FIGS.

MARINE SEDIMENTATION AND OIL ACCUMULATION ON GULF COAST. I. PROGRESSIVE MARINE OVERLAP[1]

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Houston, Texas

ABSTRACT

A large part of the Gulf Coast petroleum reserves are in transgressive sands. The history of a marine transgression is presented, and is illustrated by a discussion and by electrical-log profiles of the Cockfield (Eocene) formation. Since a transgressive sand presents conditions favorable for the migration, accumulation, and recovery of petroleum, it is advised that both local and regional studies be made of producing horizons in light of the theory of marine overlap.

During recent years the attention of petroleum geologists has been turning from a concentrated search for structural traps for oil, to an investigation of the possibilities of stratigraphic traps. There are numerous types of stratigraphic reservoirs,[4,5] but the writers have chosen to discuss first the "progressive marine overlap" type, since it is this feature which appears to have caused much of the Gulf Coast stratigraphic accumulation of petroleum. According to John Miller of The Texas Company,[6] more than 90 per cent of the oil produced on the Gulf Coast comes from sands at the base of marine transgressions. Among these may be included the upper Wilcox, the "Cockfield," *Marginulina*-Frio, and lower Miocene producing sands.

Sedimentation during marine advance is discussed here in relation to oil accumulation. The subject is treated under simple, ideal conditions, without reference to the complications resulting from structure, either before or after deposition. The fundamental concepts of this type of sedimentation are easily applicable to the Gulf Coast stratigraphy by use of electrical-log profiles, paleontologic and lithologic correlations, and isopach maps. The existing conditions may be illustrated diagrammatically and interpreted to show the relationship between fact and theory.

A study of the sediments which have been deposited during Gulf

[1] Read before the Houston Geological Society, October 10, 1940. Manuscript received, April 15, 1941. Published with permission of the Republic Production Company and the Speed Oil Company.

[2] Fohs Oil Company. Formerly geologist, Speed Oil Company.

[3] Geologist, Republic Production Company. Now Mrs. Dorothy Jung Echols.

[4] M. T. Halbouty, "Probable Stratigraphic Traps in the Gulf Coast," *World Petroleum*, Vol. 9, No. 6 (1938), pp. 27–39.

[5] A. I. Levorsen, "Stratigraphic Versus Structural Accumulation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 5 (1936), pp. 521–30.

[6] Personal communication.

Coast Tertiary time shows that the sea has maintained various positions bordering the land mass, advancing and retreating in major or minor fluctuations. At present, it is even possible that more continental area is exposed than ever before during geologic time. Throughout the past, however, various parts of the now existing continents

FIG. 1.—Surface geology of part of Gulf Coastal Plain.

have been covered by the sea. The changing relationship of the sea and land is the result of a constant effort to maintain an equilibrium between the amount of sediment removed from one place and deposited in another. Since the processes of erosion and deposition are constantly active, the position of the land and sea is never stationary.

By a marine transgression is meant the inland movement or advance of the sea which results in a sequence of sediments called a progressive marine overlap. The resultant stratigraphic feature represents

the overlapping of older formations by younger formations shoreward. As the sea moves landward, deposition takes place farther and farther inland.

The Gulf Coast Tertiary represents a series of such marine transgressions. The Midway, upper Wilcox, parts of the Claiborne, Jackson, marine Oligocene, and marine Miocene formations have been deposited during major transgressions. Each transgression from older to younger has less inland extent, and each one is interrupted by a retreat. Therefore, it is apparent that the amount of tilting of the land mass determines the extent of the transgression, whereas the seaward transportation of sediments initiates the retreat. This history may be interpreted from a study of the Gulf Coast Tertiary stratigraphy which will show that the outcrop of each succeeding younger formation is nearer the present shoreline, and each marine invasion is followed by a regression during which non-marine deposition took place.

Such an advance, or transgression, may be the result of several causes. The causes are discussed briefly here, since whatever the cause, the resulting stratigraphic picture is essentially the same under ideal conditions. Relative lowering of the land and raising of the sea-level over an entire ocean coast (or eustatic adjustment) may be one cause; tilting, or dynamic adjustment, another. Many Gulf Coast geologists believe, too, that intermittent climatic changes caused the several temporary transgressions of the sea in the coastal area during Tertiary time. Climatic changes resulting in (1) marked decrease in the rate of sedimentation, or (2) locally, excess of rate of erosion of the land margin over rate of withdrawal of the sea, may cause what appears to be a transgression during a period when the sea is in a normal stage of retreat.

The effect of climatic changes may be illustrated by postulating the following history.

(1) Assume a land mass which supplies sediment to an adjacent advancing sea. The rivers remove detritus from the land and deposit it in the sea which works over and sorts the material. The quantity of sediment laid down is dependent on (a) the amount of detritus available, and (b) the ability of the streams to carry it. Until a profile of equilibrium is reached, deposition continues, and theoretically, the sea continues to advance toward its ultimate, though unattainable, goal of covering the entire lithosphere.

(2) Assume, however, that over a long period of time the rainfall increases, thus increasing the volume of water flowing in the streams, or otherwise increase the streams' carrying capacity.

(3) The increased influx of sediments causes filling of bays and la-

goons, and the strand line is ultimately pushed farther seaward by the formation of deltas. Thus, a retreat of the sea is effected.

(4) When base levels of erosion and deposition are approached, the

FIG. 2.—Index map. AA' line of electrical-log profile.

rate of sedimentation is again decreased. The sediments are redistributed over the ocean floor, and the sea proceeds to readvance over the newly formed deltas and over the land mass which has been lowered by erosion.

Hence, a decrease in the rate of sedimentation restores the transgression which was interrupted by a minor regression, and a new cycle

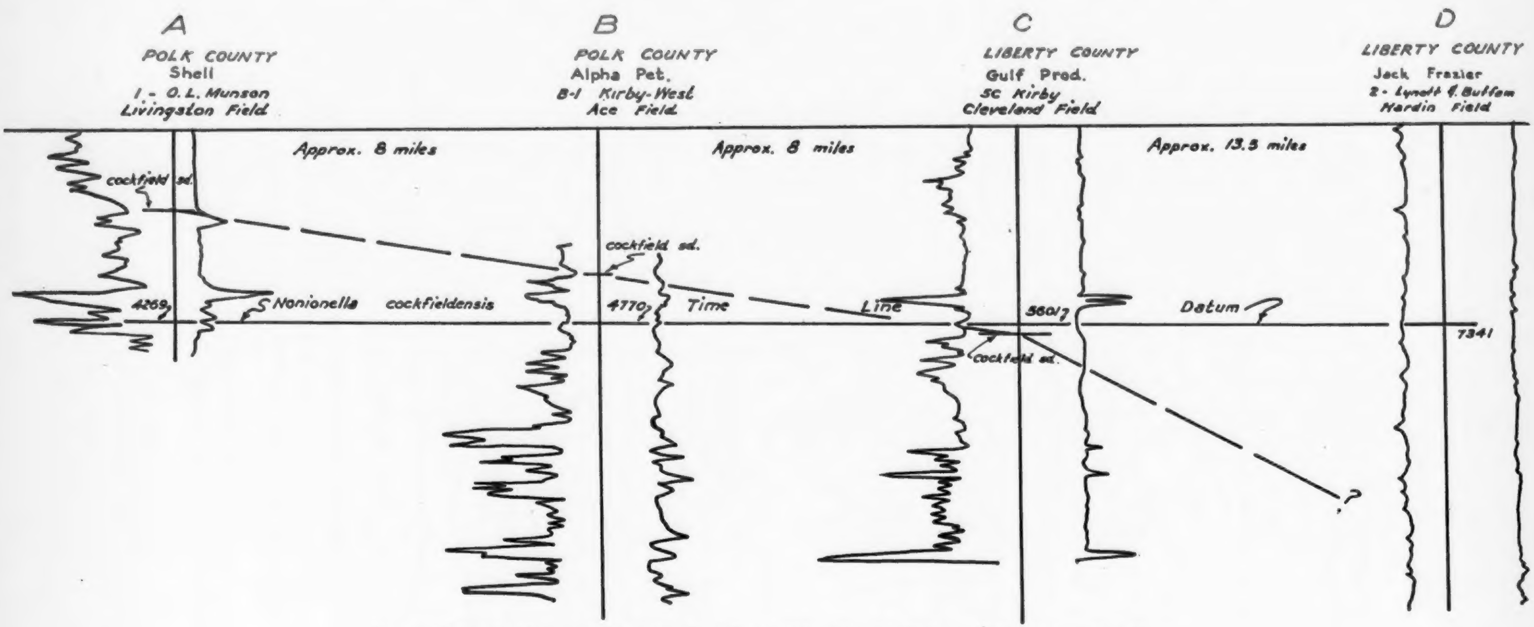

FIG. 3.—Electrical-log profile showing Cockfield section through Polk and Liberty counties, Texas.

of erosion and deposition is initiated. If, during stage number 3 of this history, the land margin is cut back locally by waves or currents, simultaneously with a more regional retreat of the sea, but at a rate (in feet per year, for example) equal to, or greater than, the rate of withdrawal of the sea, effects similar to those of a transgression may be observed.

The "Cockfield"[7] formation of Eocene age, containing one of the prolific oil-bearing sands of the Gulf Coast, shows that it has been deposited at the beginning of a marine transgression. The marine beds which appear at the top of the Yegua section, and are characterized by *Nonionella cockfieldensis*, represent the initial advance of the sea after the regression of Yegua time, and before the major transgression of Jackson time.

The sand is generally rather fine-grained and homogeneous in texture, composed largely of quartz grains. Downdip it passes into sandy shale and shale. Above the sand are also sandy shales and shales, and glauconite is found well developed. In many places, the strata overlying the sand can be zoned lithologically for about 200 feet, a fact indicative of regularity in depositional conditions. Below the sand are brackish-water shales, sandy shales, and lignites of the Yegua, which grade downdip into marine shales. In some wells a thin sand body above the main sand is encountered shortly before the main sand is reached. This probably signifies minor fluctuations in the strand line. The diagnostic fossil, *Nonionella cockfieldensis*, is found either in, at the top of, or above, the sand. The included diagrams show that the features expectable in a transgressive sedimentary sequence are the same as those which have been described for the Cockfield formation.

Figure 2 illustrates the line of section through which the electrical log profile on Figure 3 is drawn. The fields projected on this profile of the Cockfield section are the Livingston and Ace fields, Polk County, Texas, and the Cleveland and Hardin fields, Liberty County, Texas. This cross section shows the Cockfield sand becoming more shaly downdip, and overlain by shale. Well A has a good sand section of approximately 70 feet in thickness. Well B has less sand; in well C shale is predominant; and in well D the Cockfield sand is almost totally absent. In each case the sand is overlain by shale. This impervious cap over the porous marine sands makes the Cockfield suitable for an oil reservoir.

The foraminifer, *Nonionella cockfieldensis*, usually chosen by pale-

[7] Name "Creola" proposed to include the *Nonionella cockfieldensis* beds. H. B. Stenzel, "The Yegua Problem," *Univ. Texas, Bur. Econ. Geol. Bull. 3945* (1940), pp. 848–910.

ontologists to determine the top of the Cockfield formation, has been identified in each of the wells. From the profile it is readily seen that this fossil is not everywhere at the top of the sand. In well A it is found

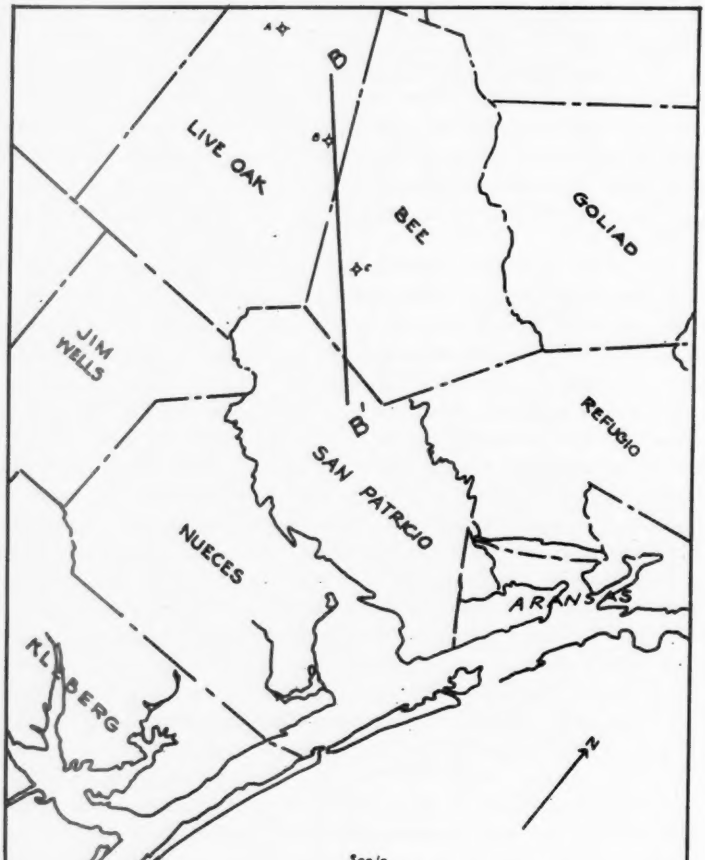

FIG. 4.—Index map. *BB'* line of electrical-log profile.

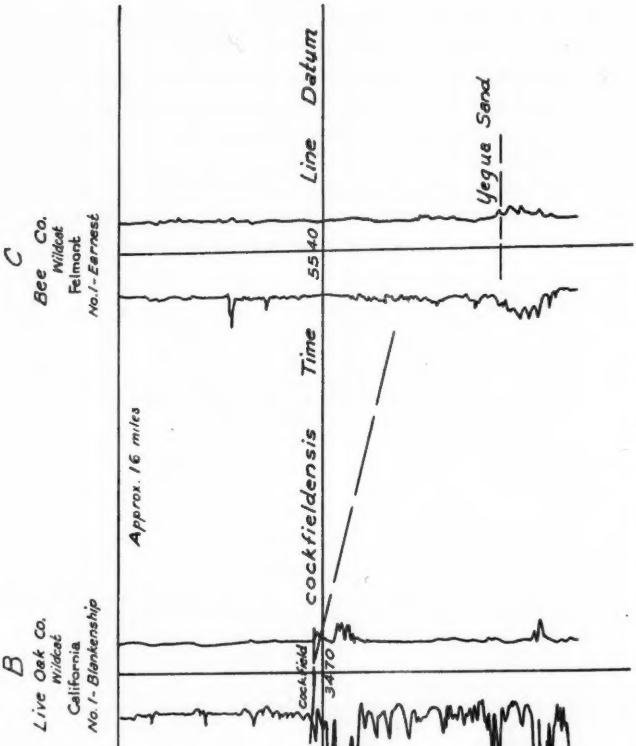

FIG. 5.—Electrical-log profile showing Cockfield section through Live Oak and Bee counties, Texas.

down in the sand section, whereas in C it is in the shale immediately overlying the sand, and in D, where no equivalent sand is present, it occurs in the shale. Apparently, then, *Nonionella cockfieldensis* existed over a broad areal extent in a sea in which sands and shales were being deposited at the same time in different places. This indicates that as each part of the sand was being laid down, a shale was being deposited downdip. Thus, the sand body known as the Cockfield can not represent a time unit, but rather a lithologic unit. No part of this lithologic unit is exactly the same age as any other part along any section normal

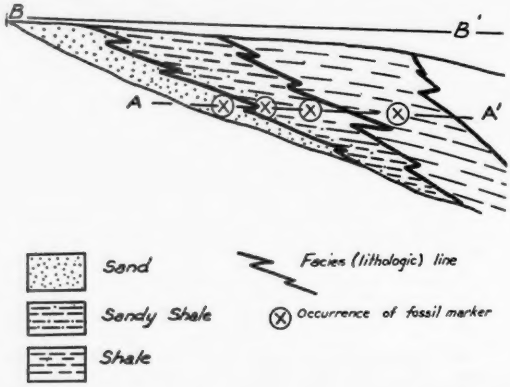

FIG. 6.—Diagrammatic section showing sedimentary sequence in progressive marine overlap. Series of sands representing succession of time units appears as continuous sand body. Interfingering sand stringers are result of minor strand-line fluctuations. *AA'*, sea-level (time line). *BB'*, sea-level, after transgression.

to the strike. The paleontological markers, representing a time unit, therefore must differ from the electrical-log correlation of the sand tops which are essentially lithologic. Thus, in dealing with a transgressive sand, it is expectable that the paleontological marker be found above the sand in the downdip wells, *if a fossil is used which did not limit its living conditions to one environment.*

Figure 4 shows the line of section in southwest Texas through which the electrical-log profile (Fig. 5) has been drawn. This illustrates the same conditions in the Cockfield section from Live Oak County through Bee County. The similarity of the two sections shown in Figures 3 and 5 is indicative of the regional trend of this marine transgression.

It is possible to explain these conditions and sedimentary features as a result of sedimentation in an advancing sea into which coarse clas-

tic sediments are being carried. Figure 6 illustrates the deposition schematically. At the shore margin, or beach, sands are being deposited. These grade outward into finer sands, sandy muds, muds, and silts. The rapidity of lithologic change from sand to mud depends on the coarseness of sediments deposited, the geomorphology of the sea floor, currents, and strength of waves. The lithologic character is primarily dependent on the source. As the edge of the sea transgresses inland, sands are left on newly formed beaches and finer sediments lie on previously deposited sands. The advancing sea will thus cause to be deposited a fairly continuous sand body, composed of successive sand units, marking each stage of the sea's landward progress. This sand

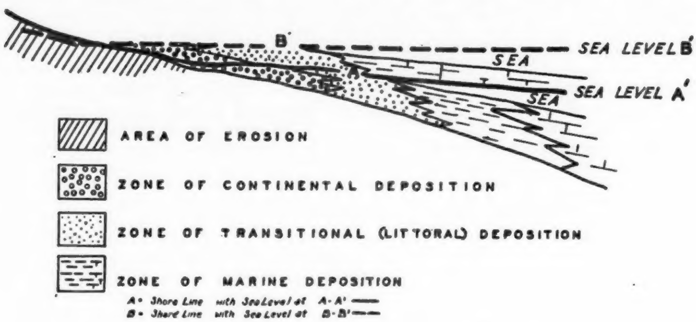

FIG. 7.—Schematic diagram of zones of erosion and deposition, showing change in position of zones in transgressing sea.

body is a lithologic unit, grading downdip into finer sands, sandy shale, and shale, and likewise grading laterally seaward into finer sediments and shale. Lithologically, the sand itself is fairly uniform in texture and mineral content, as the advancing sea reworked and resorted each of the sands it passed over. Thus, the coarse sands should be porous and permeable because of the uniformity of grain size. The updip limit of the marine sand marks the farthest advance of the sea. Beyond this is a transition zone, grading into continental deposits. The relation of the zones of erosion and (or) non-marine and marine deposition is shown in Figure 7.

As has been pointed out, the less pervious seal of marine shale overlying the porous marine sand results in a stratigraphic sequence ideal for the trapping of oil. Furthermore, the fact that the sand bodies are continuous in a transgressive series is of importance in the search for petroleum reserves. The stratigraphic sequence resulting from a marine invasion should be favorable for the migration of oil as well as ac-

cumulation, since the petroleum originates in the shales and must migrate laterally only a short distance to reach the adjacent sands. The source beds then represent the same age or time unit as the reservoir sands. In addition, the lithologic character of the overlap sands is satisfactory for the recovery of whatever oil accumulates, because of opportunities for favorable porosity and permeability.

Since the marine overlap presents conditions well suited for a petroleum reservoir, the writers believe it is advantageous to make local and regional studies of possible producing zones with a view to deciding whether they are transgressive in origin. When this is done, it may be possible to determine the updip and downdip limits of marine sandy zones from which oil may be produced.

ACKNOWLEDGMENTS

The writers appreciate the assistance of John Miller and I. I. Gardescu of The Texas Company for criticism of the manuscript. The figures were drafted by Jo. R. Lodle of the Republic Production Company.

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HEART MOUNTAIN AND SOUTH FORK THRUSTS, PARK COUNTY, WYOMING[1]

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ABSTRACT

The Heart Mountain thrust sheet of northwestern Wyoming is traceable from Clark Fork Valley southward across Sunlight Basin and across the North and South forks of the Shoshone River. If it continues still farther southward into the northwestern part of the Wind River Basin, as appears possible, its linear extent is more than 90 miles. The thrust sheet moved eastward a distance of more than 36 miles, much of which was across the surface of the land.

The South Fork thrust is beneath, and is older than, the Heart Mountain thrust. The rocks of the South Fork overthrust sheet are sedimentary formations of Jurassic and Cretaceous age, whereas those of the Heart Mountain thrust sheet are limestones and dolomites of Paleozoic age. A trough-like fold of the South Fork thrust sheet, which appears to have been downfolded after the thrusting, lies in the valley of the South Fork of the Shoshone River. It is 8 miles in length and bounded at both ends by transverse faults. The rocks in the trough have been folded into a syncline and a recumbent anticline presumably formed during the emplacement of the thrust. Northeastward from the South Fork of the Shoshone, the thrust extends as a low-angle fault into the Shoshone Reservoir, where it is thought that the inclination and trend change abruptly, and that the fault thence continues to the northwest up Rattlesnake Valley as a high-angle shear fault.

On the basis of structural deformation, the Wasatch formation of this region is divisible into two units. The emplacement of the South Fork thrust followed the deposition of the earlier unit and the emplacement of the Heart Mountain thrust followed the deposition of the later unit. After the emplacement and partial erosion of the Heart Mountain thrust sheet the tuffaceous sediments and volcanic rocks comprising the "early basic breccia" of the region were deposited.

Vertebrate fossils from beds below the Heart Mountain thrust and others from beds above the thrust indicate that the thrusting took place near the close of the lower Eocene. The South Fork thrust was formed some time earlier in the Eocene.

INTRODUCTION

The Paleozoic limestones and dolomites that form the upper parts of Sheep, Logan, and Heart Mountains were first recognized as parts of a great overthrust sheet by Dake[3] in 1916. Three years later Hewett[4] interpreted blocks of Madison limestone (Mississippian) that rest on beds of middle Eocene age in the McCulloch Peaks region as a part of the Heart Mountain thrust. This interpretation extended the known minimum amount of horizontal movement of the overthrust from 16 to 28 miles. In 1933, Bucher advanced for consideration the possibility that "the limestone plates which constitute the thrust masses of this

[1] Published by permission of the director of the Geological Survey, United States Department of the Interior.

[2] United States Geological Survey.

[3] C. L. Dake, "The Heart Mountain Overthrust and Associated Structures in Park County, Wyoming," *Jour. Geology*, Vol. 26 (1918), pp. 45–55.

[4] D. F. Hewett, "The Heart Mountain Overthrust, Wyoming," *ibid.*, Vol. 28 (1920), pp. 536–57.

region were thrust eastward and scattered much as they exist today by the horizontal component of the force of a large volcanic explosion."[5] Johnson, who had mapped Rattlesnake and Cedar Mountains in 1931–32, comments as follows on the origin of the Heart Mountain thrust,[6] ". . . it is not thought necessary to invoke any singular cause of overthrusting such as that suggested by Bucher." In 1933 Sheets mapped in detail that part of the overthrust known as Logan

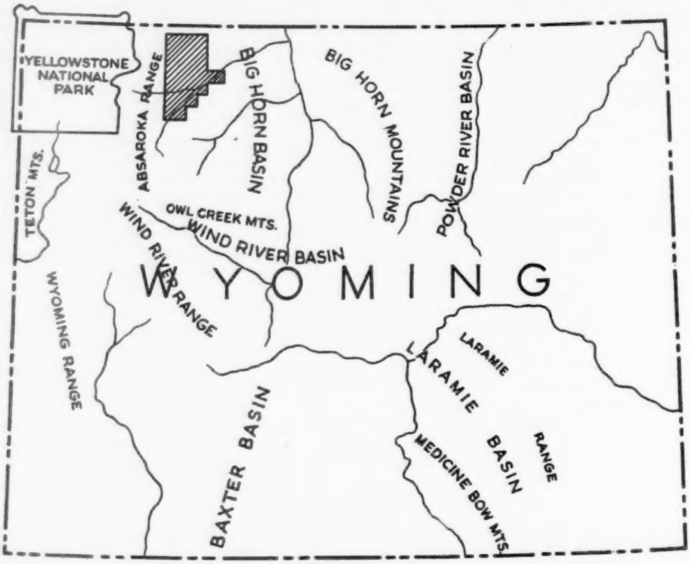


FIG. 1.—Index map of Wyoming, showing location of area described (cross-lined).

Mountain and published a short paper on the structural details near the western border of the thrust sheet (Fig. 2). His paper does not discuss the Heart Mountain thrust problem as a whole, but does introduce a new conclusion, namely, that the small-scale structural features in the sedimentary rocks adjacent to the volcanic rocks are certainly later than the major thrust and are the result of forces set up by the extrusion of the volcanic rocks.[7] In 1933 and 1934 Stevens mapped the

[5] W. H. Bucher, "Volcanic Explosions and Overthrusts," *Amer. Geophys. Union Trans.*, 14th Ann. Meeting, 1933, p. 239, Nat. Research Council, June, 1933.

[6] G. D. Johnson, "Geology of the Mountain Uplift Transected by the Shoshone Canyon, Wyoming," *Jour. Geology*, Vol. 42, No. 8 (1934), p. 832.

[7] M. M. Sheets, "Structural Detail near the Western Border of the Thrust Sheets North of Shoshone River, Wyoming," *Amer. Jour. Sci.*, 5th Ser., Vol. 29, No. 170 (1935), pp. 144–50.

Sheep Mountain thrust remnant, and from his study he concluded "that the Heart Mountain thrust is the easternmost of the great belt of Rocky Mountain thrust faults."[8]

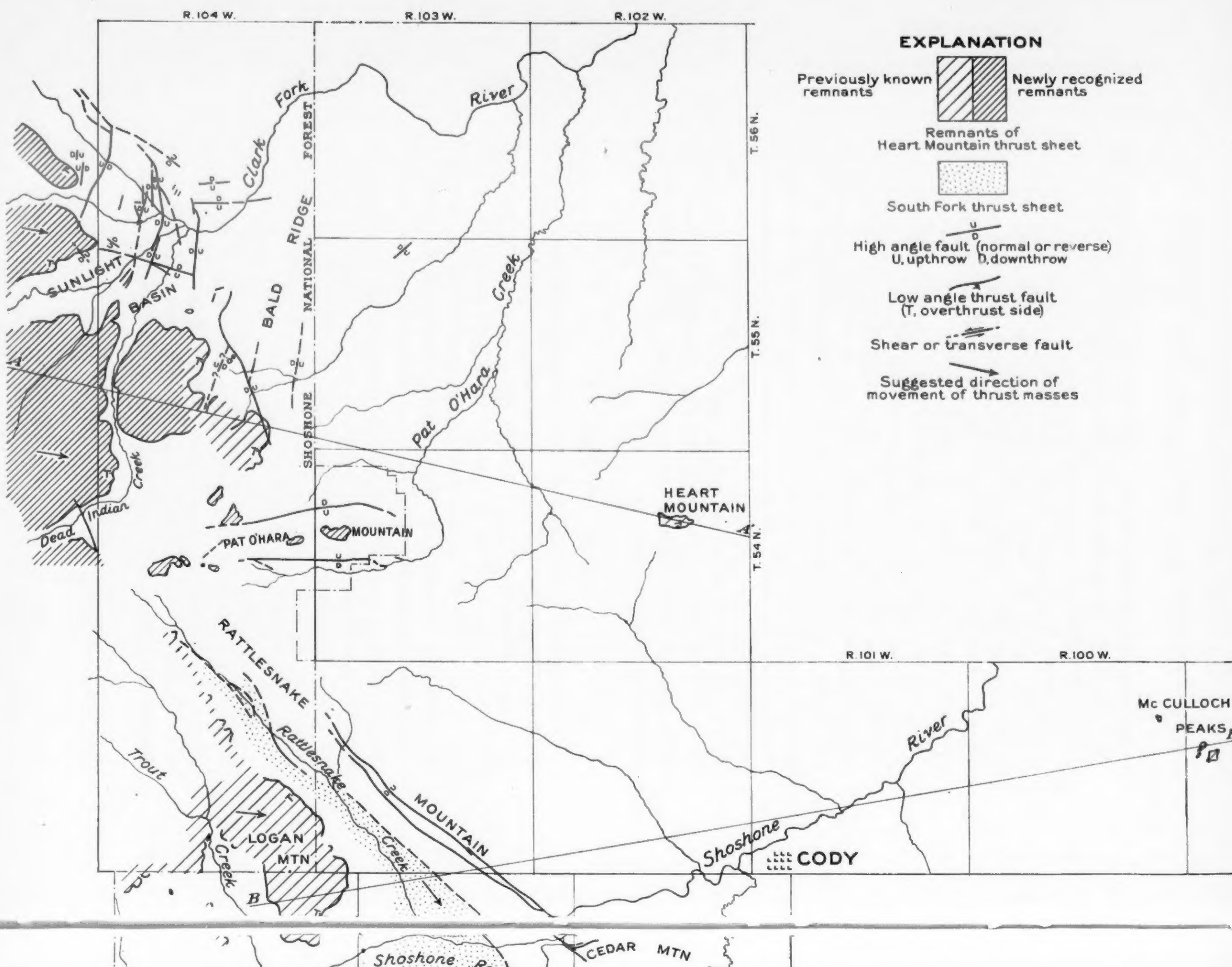
Field work by the writer on the western side of the Big Horn Basin and in the area of the Heart Mountain thrust began in 1935, and was continued through the field seasons of 1936, 1937, 1938, and 1940. The writer is indebted to R. P. Bryson, F. M. Haase, K. E. Lohman, R. R. Rosenkrans, and W. C. Warren for mapping parts of the area, and to D. A. Andrews, Paul Averitt, and H. D. Miser for critical reading of the manuscript. The area mapped extends southward from the Montana-Wyoming line across Sunlight Basin and the North and South forks of Shoshone River to Carter Mountain, and extends as far east as McCulloch Peaks. Aerial photographs of the Shoshone National Forest were available for part of the area; the remainder was mapped by plane table on a scale of 2 inches to the mile. This paper is offered only as a summary of the structural observations regarding the two overthrusts, together with essential data that have a direct bearing on them. A report covering the other phases of geology investigated, together with detailed areal and structural maps, will be prepared for publication at a later date.

HEART MOUNTAIN THRUST

Areal extent.—The known remnants of the Heart Mountain thrust, at the time the present investigation was begun, include Sheep Mountain, Logan Mountain, a small mass at the south end of Bald Ridge, and small outliers at Heart Mountain, McCulloch Peaks, the northeast end of Carter Mountain, and the northwest end of Rattlesnake Mountain (Fig. 2). Additional remnants discovered during the present investigation have increased the total area occupied by the individual remnants from 25 to 55 square miles. The discovery of remnants at the northwest end of Rattlesnake Mountain, on Pat O'Hara Mountain, and in Sunlight Basin has increased the north-south extent of the thrust from 27 to 36 miles. Additional mapping will probably extend the thrust a considerable distance farther northwest.

Character of thrust sheet.—The formations involved in the thrust are the Bighorn dolomite of Ordovician age; undifferentiated dolomites, limestones, and shales of Devonian age; and the Madison limestone of Mississippian age. Not uncommonly, however, the Ordovician and Devonian rocks are absent, and the Madison limestone forms the base

[8] E. H. Stevens, "Geology of the Sheep Mountain Remnant of the Heart Mountain Thrust Sheet, Park County, Wyoming," *Bull. Geol. Soc. America*, Vol. 49, No. 8 (1938), p. 1265.



EXPLANATION
Previously known remnants
Newly recognized remnants
Remnants of Heart Mountain thrust sheet
South Fork thrust sheet
High angle fault (normal or reverse) U, upthrow D, downthrow
Low angle thrust fault (T, overthrust side)
Shear or transverse fault
Suggested direction of movement of thrust masses
R. 104 W.
R. 103 W.
R. 102 W.
R. 101 W.
R. 100 W.
T. 56 N.
T. 55 N.
T. 54 N.
T. 53 N.
Clark Fork River
Pat O'Hara Creek
SHOSHONE NATIONAL FOREST
BALD RIDGE
SUNLIGHT BASIN
Dead Indian Creek
PAT O'HARA MOUNTAIN
HEART MOUNTAIN
RATTLESNAKE MOUNTAIN
Rattlesnake Creek
Trout Creek
LOGAN MTN
Shoshone River
CODY
Mc CULLOCH PEAKS
CEDAR MTN
Shoshone Res
A
A'
B
B'

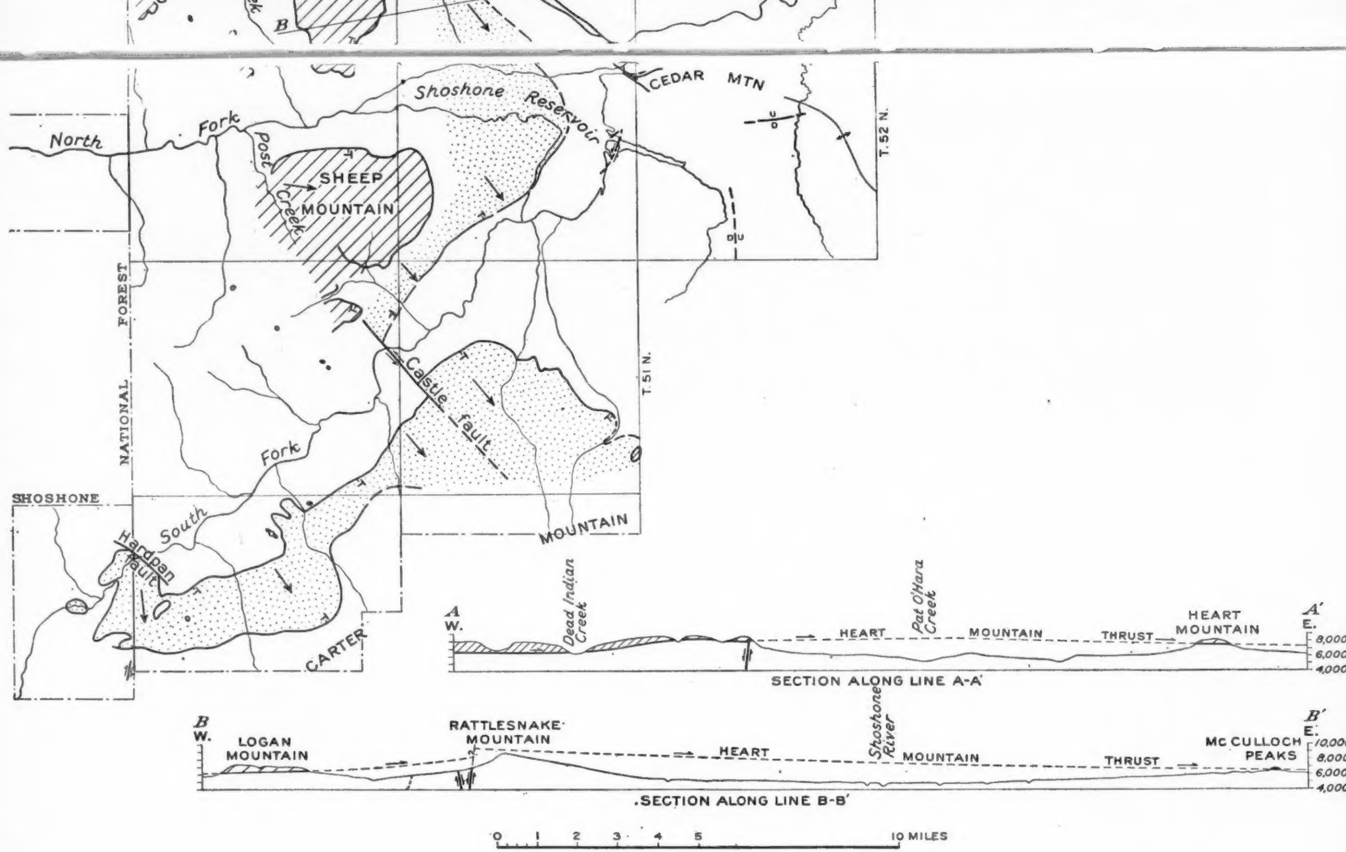


FIG. 2.—Map and cross sections, showing location of remnants of Heart Mountain thrust and their relation to South Fork thrust.

of the thrust sheet. The combined thickness of these three units is not more than 1,700 feet. The beds constituting the thrust sheet are, in general, nearly horizontal. The thickness of the eroded remants of the thrust sheet ranges from 700 to 1,000 feet, with a maximum of 1,300 feet. In Sunlight Basin the thrust sheet is cut by many high-angle faults that do not extend into the underlying beds; apparently they were formed during the emplacement of the thrust. The Logan Mountain and Sheep Mountain blocks, on the other hand, are cut by relatively few faults.

Base of thrust.—In Sunlight Basin area the sole of the advancing thrust lay below the surface of the land, but east and south of Sunlight Basin the thrust sheet moved across an erosion surface—apparently one of low relief—probably not far above the Tatman or Cottonwood bench, the highest stream-planed surface in the Big Horn Basin. Since the emplacement of the thrust sheet it has been deformed by faulting, by subsidence, and by uplift from the intrusion of volcanic breccia. Altitudes of the base of the thrust sheet range from 6,100 to 7,500 feet above sea-level in the Logan Mountain area, and from 6,600 feet in Sunlight Basin to 8,000 feet on Bald Ridge and to more than 9,000 feet on Pat O'Hara Mountain. Talus débris and slope wash cover the trace of the fault plane in most places, so that the thickness of the fault gouge or thrust breccia is not easily determined. One of the best exposures of the fault is in the triangular remnant at the southern tip of Sheep Mountain. At the eastern point of that block the fault zone is 25–30 feet thick. There the zone is composed of uncemented fragments of limestone and dolomite, some of which measure several inches across but most of which do not exceed one inch. The fragments are imbedded in a matrix of yellow-gray calcareous rock flour. Fifteen hundred feet southwest of the aforementioned locality, beds belonging to the Wasatch formation are exposed to within 10 feet of the overlying dolomite of the thrust sheet, so that there the fault breccia is not more than 10 feet thick. At some places the impression is gained that the fault breccia is usually much thicker. On this subject Dake commented as follows: "The fault contact is practically everywhere concealed by talus from the Madison cliffs, but at several places it could be located within a few feet, and the zone of crush breccia is notably thin at most points."[9]

On the north side of Heart Mountain the Wasatch strata, immediately below the thrust plane, exhibits an uncommon feature which has been described by Stevens.[10] The shale and sandstone beds below the

[9] C. L. Dake, *op. cit.*, p. 52.
[10] E. H. Stevens, *op. cit.*, pp. 1259–60.

Fig. 3.—Sheep Mountain remnant of Heart Mountain thrust, looking west-southwest from Shoshone dam. Paleozoic limestones and dolomites form steep cliffs, with thrust fault at base; slumped masses of Cody shale below. Shoshone Reservoir in foreground and valley of North Fork of Shoshone River on right (photo by K. E. Lohman).

Fig. 4.—North side of Sheep Mountain. Heart Mountain thrust fault is at base of cliff-forming Paleozoic limestones and dolomites. Slumped débris below fault is mostly Cody shale. Knob on skyline at upper right is volcanic rock. North Fork of Shoshone River in valley in foreground.

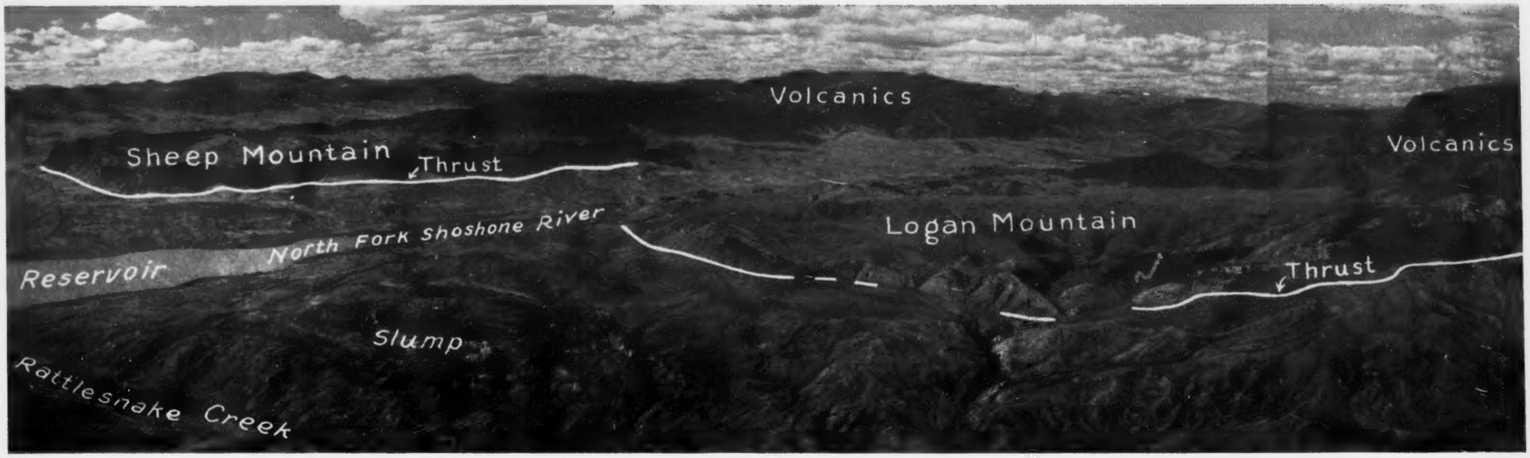


FIG. 5.—Sheep Mountain and Logan Mountain remnants of Heart Mountain thrust, looking southwest from crest of Rattlesnake Mountain.

plane have been squeezed and macerated, and into them many well rounded cobbles of limestone and quartzite have been introduced during the deformation of the beds. The cobbles are apparently derived from the Wasatch formation and were rounded prior to the faulting, but the movement of some cobbles against adjoining ones during the faulting shattered many of them. They are scattered like plums in a pudding in the matrix of shale and sandstone through a thickness of more than 75 feet. This type of fault breccia, however, was not observed elsewhere and is probably due to special local conditions.

A body of conglomerate associated with the fault is found in the vicinity of Dead Indian Creek. Its 150-foot thickness is composed of well rounded pebbles and cobbles of limestone and dolomite which contain both Devonian and Mississippian fossils. Apparently they were eroded from the thrust sheet and deposited by a stream near the front of the sheet and later overridden by it.

Strata below thrust sheet.—In the Sunlight Basin area the thrust sheet rests on Paleozoic rocks, but east and south of the basin it rests on an erosion surface which truncates beds ranging in age from Paleozoic to Tertiary. The easternmost remnants of the thrust—that is, those on McCulloch Peaks and Heart Mountain—rest on nearly horizontal beds of sandstone and shale belonging to the Wasatch (Eocene) formation. The Sheep Mountain and Logan Mountain remnants and the small remnant in the southeast part of T. 51 N., R. 103 W., rest mostly on Wasatch beds, but in some places rest on the Cody shale (Upper Cretaceous). The thrust remnants on the northwest end of Rattlesnake Mountain, on Pat O'Hara Mountain, on Bald Ridge, and in Sunlight Basin, lie mostly on rocks of Paleozoic age; only a few areas there are underlain by Chugwater (Triassic) or Wasatch.

The structure of the area overridden by the thrust includes the large anticlinal folds of Rattlesnake and Pat O'Hara mountains and the smaller Shoshone anticline near Cody. These folds were in existence at the time of the overthrusting.

The principal structural and depositional events preceding the emplacement of the Heart Mountain thrust are summarized thus. 1. The Fort Union and older formations were subjected to compression and thrown into numerous anticlinal and synclinal folds. 2. This structural deformation was followed by erosion and then deposition of lower Wasatch strata. 3. Renewed compression, perhaps of local rather than regional extent, led to the formation of the South Fork thrust. 4. This was followed by deposition of younger Wasatch beds, then by erosion, and finally by the Heart Mountain thrust.

Amount and direction of thrusting.—The present investigation has

not greatly increased the known minimum amount of horizontal displacement; 28 miles is the amount calculated from the data available to Hewett, whereas additional information now increases this calculation to 34 miles. The direction of thrust is, in general, from west to east, possibly toward the east-southeast. Stevens,[11] who made a detailed study of the Sheep Mountain remnant, thinks it probable that the thrust mass moved from southwest to northeast and that the minimum horizontal movement in this direction was 48 miles.

Source of thrust.—One of the puzzling questions concerning the Heart Mountain thrust is "Where did it come from?" There is no belt of intensely deformed rocks immediately west of the known remnants unless such a belt is now concealed by the volcanic rocks of the Absaroka Mountains. The Sheep Mountain and Logan Mountain remnants of the Heart Mountain thrust do not furnish much information on this question either because they are terminated on the west by intrusive volcanic breccia, or the thrust is concealed by overlying volcanic rocks.

The trace of the thrust from Bald Ridge westward to Dead Indian Creek descends rapidly from an altitude of about 8,000 feet to 6,600 feet—a drop of 1,400 feet in 4 miles (Fig. 2, section AA'). The westward slope of the fault plane then becomes nearly horizontal and continues beyond the western boundary of the area examined. In the valley of Sunlight Creek the fault plane descends westward until it reaches the floor of the valley; whether it actually extends downward below the valley floor is not known because it is concealed by a large glacial moraine. It seems reasonable, however, to assume that the thrust does disappear beneath the bed-rock surface not far west of the area mapped.

Possible southward extent.—Stevens, in his search for evidence determining the extent of the Heart Mountain thrust, made a brief trip along the east front of Carter Mountain and along the base of the volcanics on the south. At three localities, shown on Figure 6, he found limestone blocks and fragments at or near the contact between the volcanic breccia and the Wasatch formation. He interpreted these as indicating that the thrust at one time extended over those areas.[12] The writer has seen some of the same areas described by Stevens and agrees with his conclusion regarding their origin. The thrust is believed, therefore, to have extended southward to the Greybull River valley. South of this valley a great mass of volcanic rocks extends eastward

[11] E. H. Stevens, *op. cit.*, p. 1262.

[12] *Ibid.*, pp. 1250–59.

from the southern end of the Absaroka Range and conceals any remnants that may be present.

Still farther south, a few miles northeast of the mouth of the North Fork of the Wind River, Love found large blocks of Paleozoic rocks in sediments of early Eocene age.[13] He discusses several hypotheses that may be advanced to explain how the Paleozoic rocks reached their present position, but favors the interpretation that they are remnants

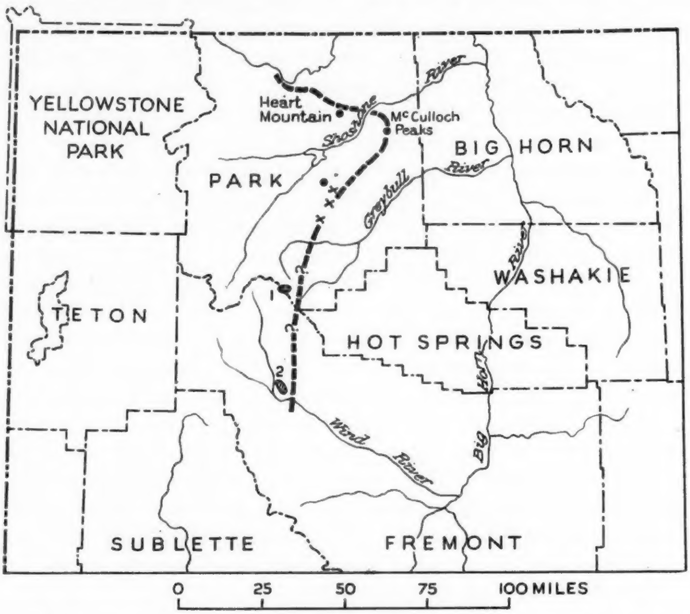


FIG. 6.—Sketch map of northwestern Wyoming, showing possible southward extent of Heart Mountain thrust. Black dots indicate easternmost outliers of thrust. Crosses indicate blocks of limestone (first noted by Stevens) which are probably remnants of thrust; 1, elevated block of Paleozoic rocks described by Rouse; 2, the "klippen" area described by Love.

of a thrust fault "and tentatively considers the Paleozoic masses to be klippen, though there is no evidence which renders this conclusion obligatory." He comments further—"In many ways, these outliers resemble remnants of the Heart Mountain thrust sheet, in the Big Horn Basin."[14] A likely place of emergence for the thrust represented by the

[13] J. D. Love, "Geology along the Southern Margin of the Absaroka Range, Wyoming," *Geol. Soc. America Spec. Paper 20* (1939), pp. 60–62.

[14] *Ibid.*, p. 107.

klippen was not found within the area mapped or examined by him. If the thrust that is postulated by Love is concomitant with, or is a continuation of, the Heart Mountain thrust, it follows that the north-south extent of the Heart Mountain thrust is more than 90 miles.

The following similarities between the thrust remnants in the Big Horn and Wind River basins are suggestive of continuity of this line of faulting: (1) the overthrust remnants in both areas consist of Paleozoic rocks; (2) sedimentary rocks of essentially the same age underlie and overlie the remnants in the two areas; (3) time of faulting is approximately the same in both areas and, although the Wind River "klippen" are perhaps slightly older than the Heart Mountain remnants, the time of faulting in both areas is probably lower Eocene.

Rouse[15] has recently described a block of Paleozoic rocks that have several anomalous features. They are the only known Paleozoic rocks in the central part of the Absaroka volcanic field, and occur at an exceptionally high altitude. The block covers an area of about a square mile and is entirely surrounded by volcanic and other igneous rocks. About 3 miles east of this block is the limestone breccia noted by Hewett[16] many years ago. The limestone described by him occurs in two zones 5–20 feet thick. The fragments are said to be angular to subangular and, if transported by water, could not have moved far from their source. The block of Paleozoic rocks described by Rouse, or other closely associated ones now concealed by volcanic material, presumably furnished the material for the limestone breccia, and therefore was in approximately its present position and exposed at the surface in Eocene time. The block of Paleozoic rocks can not be identified as a part of the Heart Mountain thrust from the data now available, but its position, as shown in Figure 6, and its anomalous features warrant exploration of such a possibility.

SOUTH FORK THRUST

Summary of previous work.—The South Fork thrust was named and described by Dake[17] in 1918. He resumed field work in the area in 1934 but his untimely death at the close of that field season came before the results of his later work had been prepared for publication. The findings and interpretations of the writer are in accord with most

[15] J. T. Rouse, "Structural and Volcanic Problems in the Southern Absaroka Mountains, Wyoming," *Bull. Geol. Soc. America*, Vol. 51, No. 9 (1940), pp. 1424–26.

[16] D. F. Hewett, "The Ore Deposits of Kirwin, Wyoming," *U. S. Geol. Survey Bull.* 540 (1914), p. 125.

[17] C. L. Dake, *op. cit.*

of the major features as outlined by Dake, but are at variance with some of the conclusions of Bucher[18] and Stevens.[19]

Dake,[20] in his interpretation of the movement of the South Fork and Heart Mountain thrust sheets, concluded that the one was driven over the other so as to produce a decken type of structure. He calculated the horizontal displacement of the South Fork thrust to be approximately 10 miles. He noted that the trace of the thrust fault was apparently shifted northwestward about a mile by a transverse fault (the Castle fault in Figs. 2 and 7). He also deduced that the thrust plane had been sharply folded along an axis nearly parallel with the South Fork Valley.

The results of Bucher's work on the South Fork thrust have not been published except for the abstract[21] of a paper presented before the Geological Society of America in 1935. He has carried on additional field studies since the publication of the abstract, but at that time was of the opinion that the beds on the southeast side of South Fork are a great landslide mass that moved by gravity down a sloping surface from a high domal land area which assumedly lay on the northwest. He states that "the beds on the south side of the river form a recumbent anticline, 8 miles long, part of which is well exposed. The anticline is a purely local structure, passing abruptly at both ends into tear faults[22] associated with sharp flexures."

To Stevens[23] after his study of the Sheep Mountain area, it seemed more likely that the structure in the part of South Fork Valley lying southeast of Sheep Mountain represents a faulted anticline. However, he specifically points out that he found no evidence that would show whether the faults are normal or thrust. The "normal" fault of Stevens (on the north side of the South Fork and northeast of the Castle fault) and the base of the "landslide" mass of Bucher (on the south side of the South Fork and southwest of the Castle fault) are interpreted by the writer to be parts of the sole of the South Fork thrust. This interpretation was first made by Dake.

[18] W. H. Bucher, "Remarkable Local Folding Due to Gravity, Bearing on the Heart Mountain Thrust Problem" (abstract), *Proc. Geol. Soc. America* (1935), p. 69.

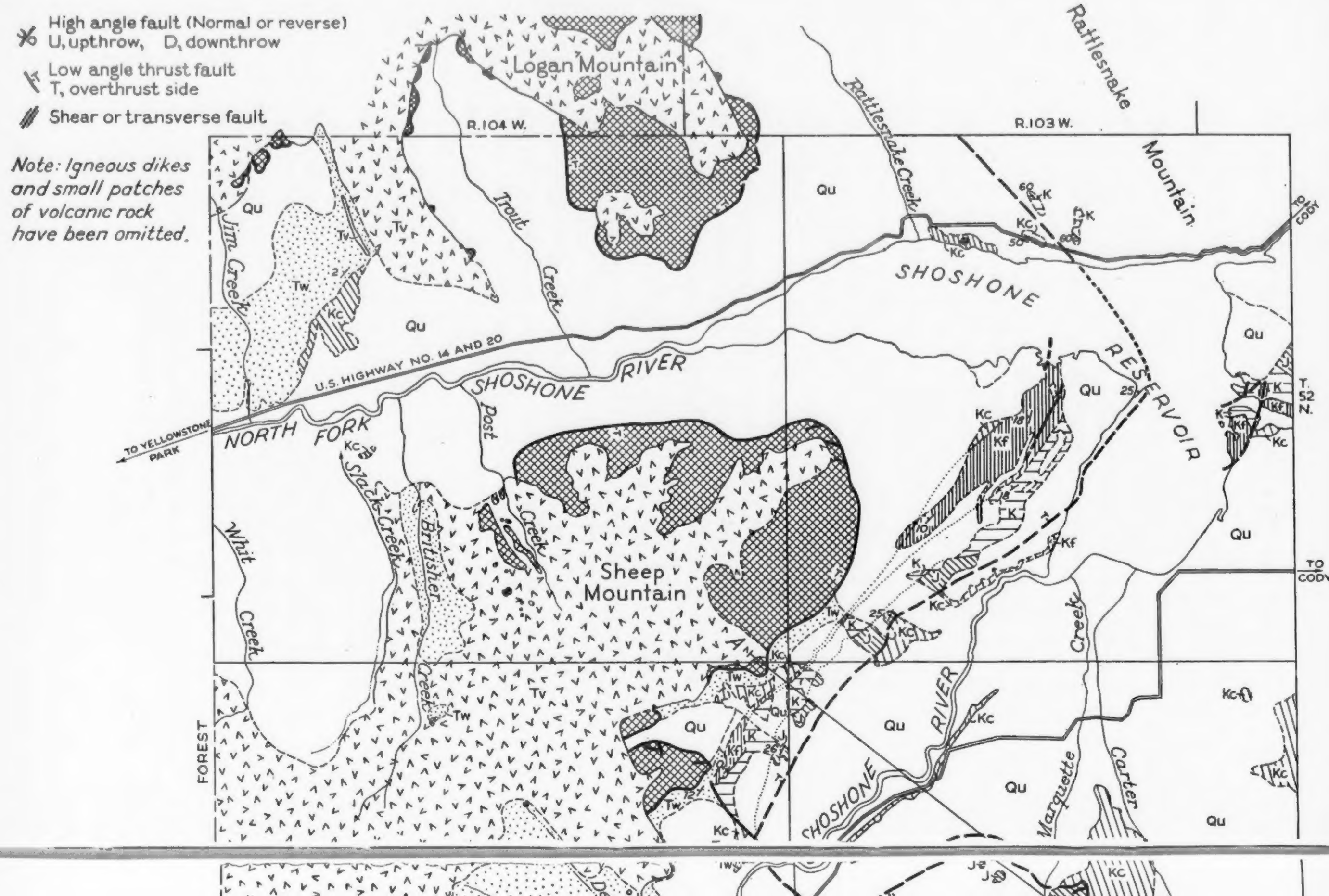
[19] E. H. Stevens, "Geology of the Sheep Mountain Remnant of the Heart Mountain Thrust Sheet, Park County, Wyoming," *Bull. Geol. Soc. America*, Vol. 49, No. 8 (1938), pp. 1233–66.

[20] C. L. Dake, *op. cit.*

[21] W. H. Bucher, *op. cit.*

[22] Apparently the Castle and Hardpan faults of my paper.—W. G. Pierce.

[23] E. H. Stevens, *op. cit.*



High angle fault (Normal or reverse)
U, upthrow, D, downthrow
Low angle thrust fault
T, overthrust side
Shear or transverse fault
Note: Igneous dikes and small patches of volcanic rock have been omitted.
Logan Mountain
Rattlesnake Mountain
Rattlesnake Creek
R.104 W.
R.103 W.
TO CODY
T. 52 N.
SHOSHONE RESERVOIR
Trout Creek
Jim Creek
U.S. HIGHWAY NO. 14 AND 20
SHOSHONE RIVER
NORTH FORK
TO YELLOWSTONE PARK
Post Creek
Slack Creek
Britisher Creek
Whit Creek
Sheep Mountain
SHOSHONE RIVER
Marquette Creek
Carter Creek
FOREST

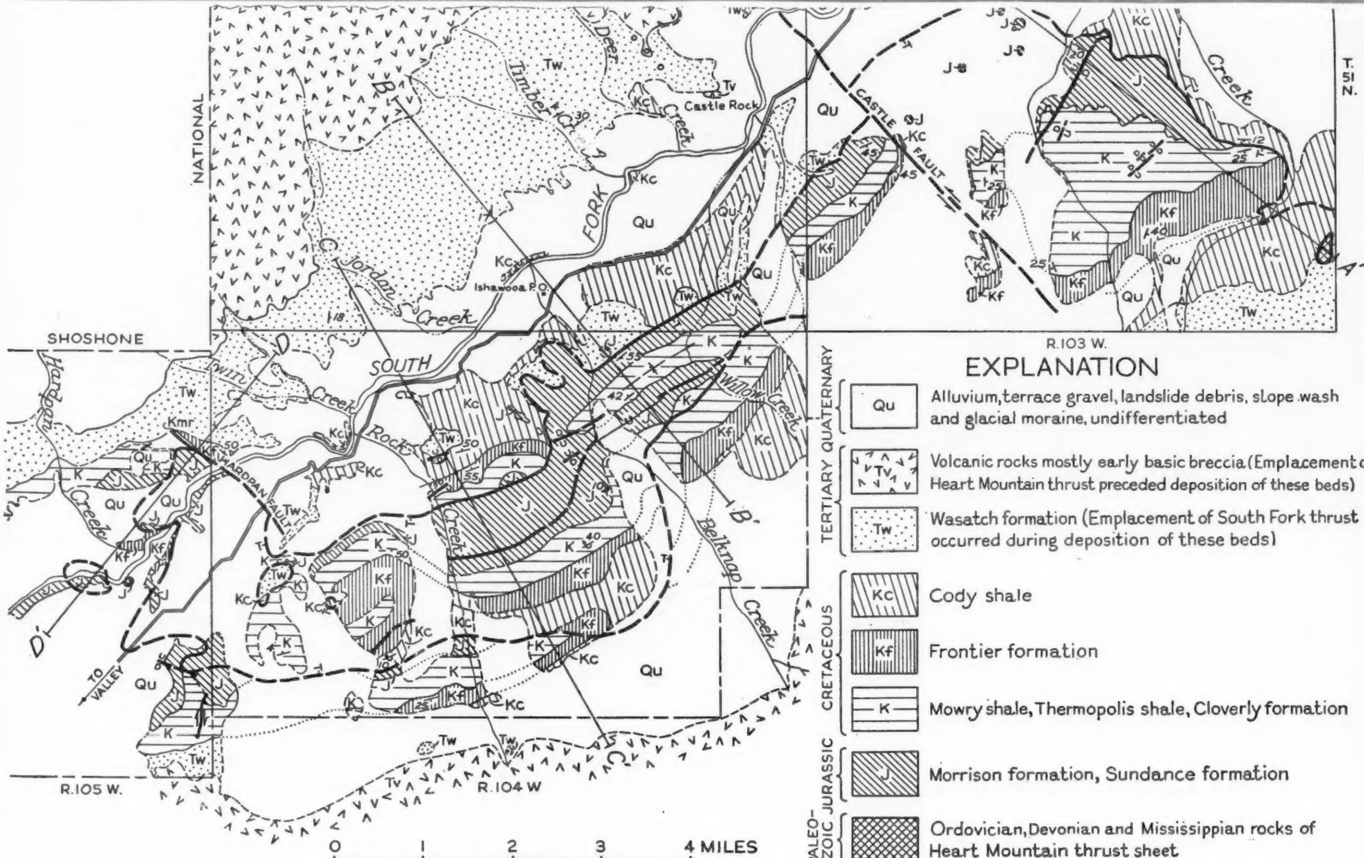


FIG. 7.—Map of South Fork thrust.

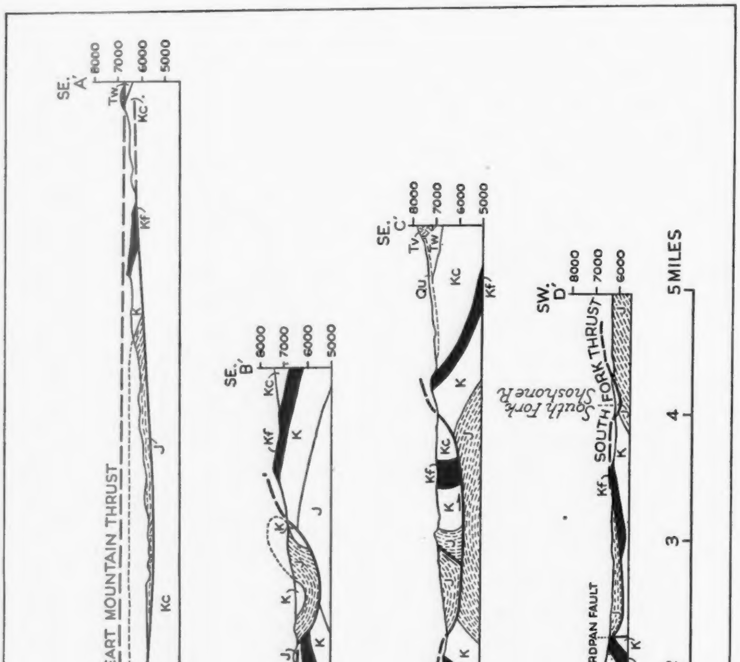


FIG. 8.—Cross sections of South Fork thrust. *Qu*, slope wash; *Tv*, volcanic rocks; *Tw*, Wasatch formation; *Kc*, Cody shale, *Kf*, Frontier formation; *K*, Mowry, Thermopolis, and Cloverly formations; *J*, Morrison and Sundance formations.

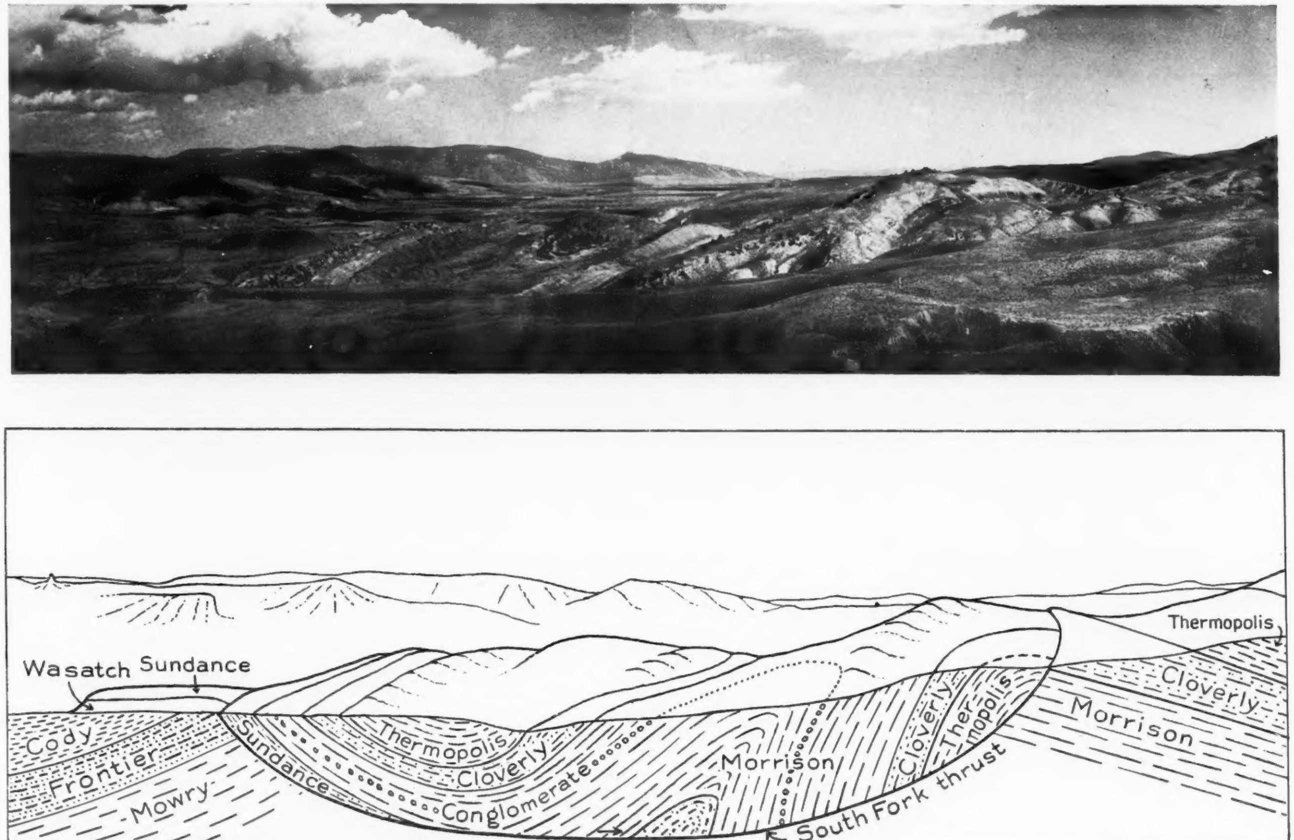


FIG. 9.—View and section looking northeast, showing South Fork thrust on east side of Belknap Creek (photo by K. E. Lohman).

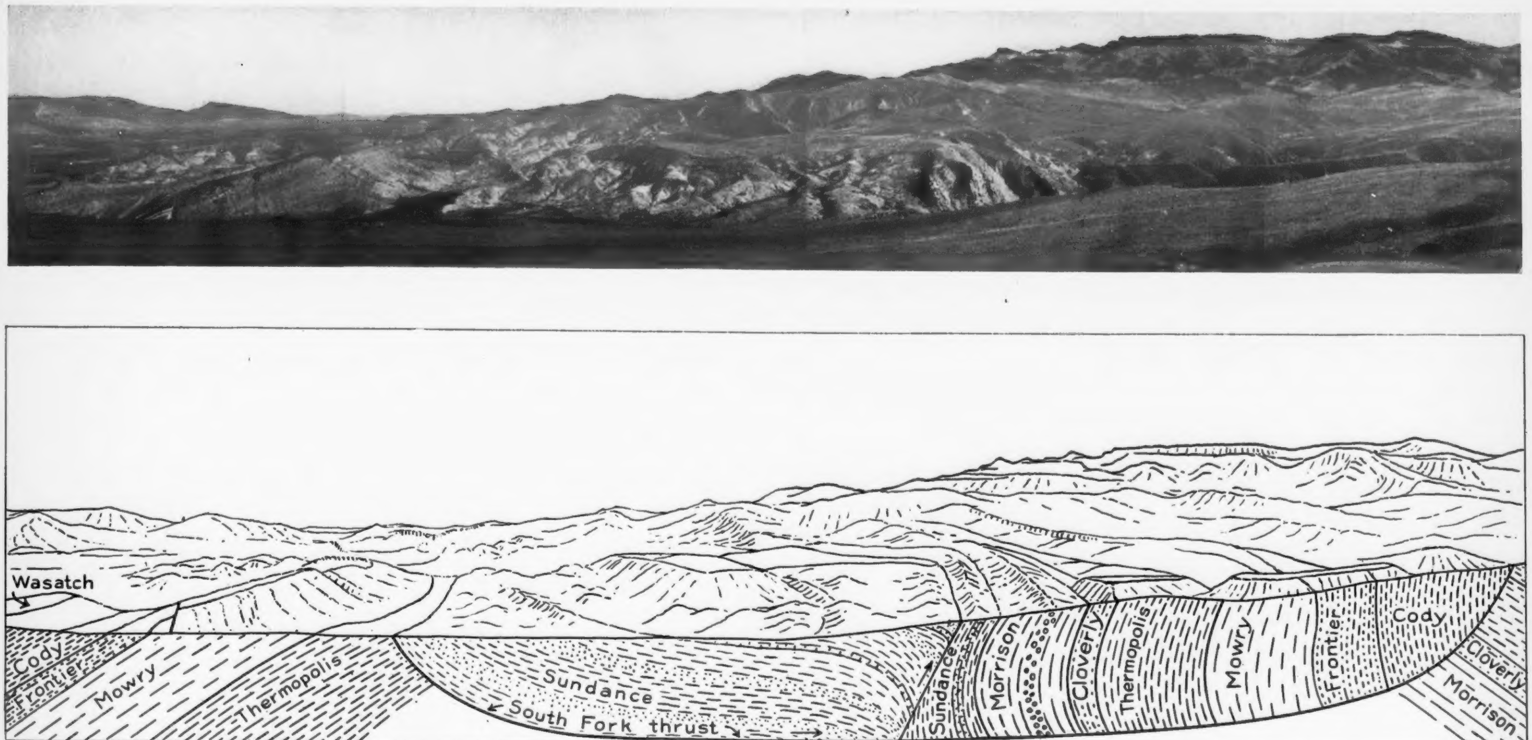


FIG. 10.—View and section looking northeast, showing South Fork thrust on east side of Rock Creek (photo by K. E. Lohman).

Stratigraphy of thrust mass.—The South Fork thrust sheet contains the following formations: the Sundance formation of Jurassic age at the base; the Morrison formation, also of Jurassic age, which is about 450 feet thick; and the Cloverly formation, 150 feet, Thermopolis and Mowry shales, 1,000 feet, Frontier formation, 500 feet, and Cody shale, 2,100 feet, all of Cretaceous age. In some places only the upper 200 feet of Sundance is present in the thrust sheet, but in other places almost the complete thickness of the formation (500 feet) is present. The full thickness of the Cody shale is not present in the thrust sheet; the maximum thickness present is about 1,200 feet. The thickness of the beds constituting the thrust sheet is thus about 3,800 feet. Most of this thickness is shale, with some sandstone beds and only a few thin limestone beds.

Structure of the thrust mass.—The principal structural feature within the thrust sheet is a recumbent anticline which is well exposed between Willow and Rock creeks. Just east of Belknap Creek the anticline is only slightly overturned (cross section *BB′* in Fig. 8), but both to the northeast and southwest the anticlinal axis passes laterally into faults (cross section *CC′*). A view of the anticlinal fold is shown in Figure 9; another view, taken farther southwest, where the anticline passes into a faulted fold, is shown in Figure 10. On the east side of Belknap Creek there is also a sharp syncline which is particularly prominent in the Thermopolis shale (Fig. 9). These structural features presumably were all formed during the initiation or emplacement of the thrust.

Northeast of the Castle fault the structure of the strata in the thrust sheet is quite different from that on the southwest side just described. The mass on the southeast side of South Fork and northeast of the Castle fault is a seemingly little disturbed unit of strata ranging from the Sundance formation (Jurassic), at the base, to the Cody shale. The beds have a fairly uniform south dip. The Sundance formation is at the base of the thrust sheet on the northwest and north sides of the mass, but as the fault is traced southeastward, successively younger formations are found at the base. The Cody shale underlies all of this part of the South Fork thrust so far as can be observed.

North of the South Fork and northeast of the Castle fault, the Sundance formation again occurs at the base of the thrust sheet and is overlain in normal stratigraphic sequence by the younger formations up to the Cody shale. Much of the surface is covered with slumped material, but where the beds are in place they show a general dip of 20°–45° NW. The thrust is underlain by horizontal Cody shale.

Base of thrust.—The part of the thrust plane that lies south of

South Fork and northeast of the Castle fault is nearly horizontal, but where viewed over an area several miles long, it is seen to be gently undulating, as shown in cross section *AA'* in Figure 8. The attitude of the fault north of the river could not be determined.

Southwest of the Castle fault the thrust mass is folded into a synclinal trough about 8 miles in length, parallel with the valley (cross sections *BB'* and *CC'* in Fig. 8). So far as can be ascertained, the dip of the fault seems to be steep on both sides of the trough, the northwest side appearing to be the steeper.

The fault zone does not seem to be very thick. It appears to be greatest where shale is adjacent to the fault, but for the most part the fault is concealed or poorly exposed. An exceptionally good view of the fault may be seen on the south side of the South Fork of Shoshone River, half a mile west of the west line of T. 50 N., R. 104 W. There the fault is confined to a zone only 2 feet thick with Frontier below and Sundance above. The fault zone contains an abundance of quartzite pebbles and boulders, many of them fractured or showing percussion marks. These hard pebbles have served as ball bearings and locally facilitated the movement of the thrust. Similar quartzite pebbles occur in the Fort Union and Wasatch formations and also probably occurred locally on erosion surfaces at the time of thrusting.

Castle fault.—The Castle fault is a shear or transverse fault trending northwest across the southwestern part of T. 51 N., R. 103 W., and the northeastern part of T. 51 N., R. 104 W. It is here named from the prominent landmark a mile southwest of the fault, known as Castle Rock—a mass of volcanic rock rising about 400 feet above the adjacent valley bottom land.

Dake[24] called the Castle fault a transverse fault. His reconnaissance mapping of it is not notably different from that shown in Figure 7. Bucher[25] called it a tear fault. Stevens[26] suggested that it is a fold which at depth passes into a fault.

The Castle fault is not a clean-cut break. On the north side of the river the beds in the South Fork thrust sheet are bent down along the east side of the fault. The drag occurs not only close to the fault, but extends to the northeast for a distance of several hundred feet. The fault zone itself is 100–200 feet wide and consists of stringers or lenticular wedges from the Thermopolis, Mowry, and Frontier formations. Of the formations that can be recognized in the fault zone, the

[24] C. L. Dake, *op. cit.*

[25] W. H. Bucher, *op. cit.*

[26] E. H. Stevens, *op. cit.*, p. 1255.

Frontier composes the greater part. The average dip of the fault seems to be about 65° SW. The Cody shale adjoins the southwest side of the fault. Its strike and dip are approximately parallel to the fault. Near the river the Cody is overlain by lower Wasatch strata, which are also steeply inclined, and it is assumed that they were thus deformed by drag along the fault. Thus the fault may be inferred to be younger than the lower Wasatch strata; on the other hand, it is older than higher Wasatch beds about 4,000 feet north of it. As interpreted by the writer, the Castle fault continues northwest beneath the higher Wasatch and also beneath the Heart Mountain thrust sheet. Hence, the movement on the Castle fault seems to have occurred within the time represented by Wasatch deposition. Such a period of structural deformation within Wasatch time is also indicated by the Hardpan fault to be described later.

South of the river the drag folds on each side of the Castle fault are striking features. Even on the generalized map shown in Figure 7 these folds are apparent, and on a detailed map they are impressive. The impression gained from them is that horizontal movement has been predominant, whereas across the river the predominant direction of movement seems to have been vertical. Additional evidence of horizontal movement on the Castle fault is provided by the trough-like fold in the South Fork thrust sheet. On the southwest side of the Castle fault the thrust plane is folded into a synclinal trough, in contrast to the nearly horizontal position of the thrust sheet on the northeast side.

The writer interprets the Castle fault as a fracture due to a compressional force, acting neither at right angles nor parallel to the fault, but applied in a direction between those two. Both horizontal and vertical movement occurred, the southwest side moving relatively downward and toward the southeast.

Hardpan fault.—The Hardpan fault is a shear or transverse fault exposed on the north side of South Fork near the east line of T. 50 N., R. 105 W. It is named from Hardpan Creek, which is 1½ miles southwest. It is similar to the Castle fault both in trend and in its relation to the Wasatch formation. The lower Wasatch beds northeast of the fault have a northeast dip of about 20°, whereas the overlying higher Wasatch beds are nearly horizontal and are not cut by the Hardpan fault.

As interpreted by the writer, the Hardpan fault has displaced the South Fork thrust sheet and forms the local northeast margin of that thrust sheet. The relationship of the fault to the thrust sheet is shown graphically in cross section *DD'* in Figure 8.

Movement along the Hardpan fault is thought to have been both horizontal and vertical. The resultant movement of the northeast side was upward toward the southeast.

Strata below thrust mass.—The South Fork thrust mass rests at most places on Cody shale, but at some places it rests on beds in the lower part of the Wasatch formation, and at a few places it lies on beds older than the Cody shale, the oldest formation being the Sundance which is revealed immediately below the fault in its westernmost exposures.

For several miles northeast of the Castle fault the strata on which the thrust rests consists of nearly horizontal Cody shale, but farther northeast on the east side of Shoshone Reservoir there are several shear faults (Fig. 7) that cut rocks older than the Cody shale. The planes of these shear faults are nearly vertical, and movement is thought to have been mostly horizontal with the west side moving southward. Presumably they formed as a result of the same force that produced the South Fork thrust.

Southwest of the Castle fault, the strata adjoining the river are horizontal. Beneath the thrust sheet, however, the beds are folded into an anticline, which is here named the Ishawooa anticline from the post-office of that name. Its trend is nearly parallel with South Fork Valley. The northwest limb of the Ishawooa anticline is well exposed east of Rock Creek (Fig. 7), where beds from Cody shale down to the Morrison are at the surface and dip northwest as steeply as 70°. The crest of the anticline is concealed by the South Fork thrust sheet, but in Rock Creek, beyond the south edge of the thrust mass, the southern limb of the anticline is revealed. Here a normal sequence of strata from Morrison to the Cody has a southerly dip of about 24°. The Ishawooa anticline was probably formed and then partly eroded prior to the emplacement of the South Fork thrust. Some additional horizontal compression of the beds in the anticline probably followed the thrust.

Source of thrust.—The part of the South Fork thrust that lies south of the South Fork of Shoshone River is a large klippe, or outlier, separated from the main thrust mass by erosion of the central part of the valley. North of the river and west of the Castle fault the thrust fault is concealed by Wasatch strata. East of the Castle fault and north of the river, the thrust fault is revealed and can be traced into Shoshone Reservoir where at low-water stage the Sundance has been observed on the Mowry shale on the west side of the south arm of the reservoir. It is not now possible, however, to trace the fault completely across the reservoir. It is thought that the fault, when followed northeastward in the reservoir, changes its trend toward the northwest, and that

the fault northwest of this bend is a high-angle fault in which the principal movement has been horizontal.

The area along the north side of the reservoir contains few outcrops. The field evidence for placing a fault there consists of extreme discordance in dips rather than any large stratigraphic break. East of the fault as drawn, the beds conform to the regional southwest dip of the strata that form the steep flank of the Rattlesnake Mountain anticline. On the west side of the fault, in road-cut exposures along the highway, the Cody shale was observed with a dip (not overturned) of 50° NE.

Farther up the valley of Rattlesnake Creek, outside the area shown in Figure 7, rock exposures are better and afford undoubted evidence of a northwest-trending fault. In that part of the valley an igneous dike or sill is cut by a northwest-trending fault and the field relations indicate that the beds on the southwest side of the fault have moved southeast about a mile. Elsewhere in the same valley are anomalous relationships which seem to demand other fault contacts. The stratigraphic relationships produced by these faults seem to call for predominant horizontal movement rather than vertical displacement. It is thought that differential horizontal movement occurred along several faults paralleling the strike of the strata, particularly in the Sundance and Morrison formations. Of course this type of faulting provides little evidence for determining its character or amount of displacement.

The Rattlesnake Mountain anticline seems to have acted as the control that determined the location and direction of movement of the South Fork thrust. As the region was subjected to further compression after the anticlinal folding of Rattlesnake Mountain, strata in the structural depression west of it yielded by faulting and the mass now constituting the South Fork thrust sheet was faulted off and thrust southeast, producing a spoon-shaped mass. The minimum horizontal displacement is $6\frac{1}{2}$ miles, and the maximum displacement may have been less than 8 miles. The maximum length of the trace of the fault probably was not much greater than the observed length of 18 miles.

TERTIARY ROCKS

Wasatch formation.—The Wasatch formation is divisible into two units, which are distinguishable primarily by their relation to the South Fork thrust. The two units were not differentiated in the field mapping, but are present north of South Fork in T. 51 N., R. 104 W., and probably occur at other places in the area. The lower unit is older than the South Fork thrust sheet, because at the number of places it

underlies the thrust—as, for example, about a mile southeast of Ishawooa, and in the window in the western part of T. 50 N., R. 104 W. The upper Wasatch unit rests upon and conceals the strata that are deformed by the Castle and Hardpan faults. These two faults displace the South Fork thrust sheet. The deposition of the upper Wasatch unit was thus later than the emplacement of the South Fork thrust. In other words, the deposition of the lower Wasatch beds was followed by the emplacement of the South Fork thrust; then came further deformation in which transverse or shear faults such as the Castle and Hardpan faults were formed; and this was followed by erosion and then by deposition of the upper Wasatch beds. Presumably these upper Wasatch beds conceal the trace of the South Fork thrust on the north side of the valley of the South Fork of the Shoshone River, west of the Castle fault.

The thickness of the two units in the Wasatch is difficult to determine and varies greatly. On the north side of North Fork and east of Jim Creek the Wasatch beds are probably 1,000 feet thick; on the north side of South Fork, in T. 51 N., R. 104 W., the Wasatch is 2,000 feet thick and possibly as much as 3,000 feet. To the southwest, however, the Wasatch thins markedly; west of Hardpan Creek it is about 500 feet thick and farther to the southwest it becomes still thinner.

J. B. Reeside, Jr., and the writer obtained a collection of fossil vertebrate teeth in September, 1938, from Sec. 7, T. 52 N., R. 104 W. The zone from which they came is approximately 400 feet above the base of the Wasatch formation in that locality. The collection has been examined by C. L. Gazin of the United States National Museum, who reports that it contains *Coryphodon*, *Eohippus*, and *Lambdotherium* cf. *popoagicum*, and is Wind River in age. In the same area Jepsen[27] found a faunule indicating Lost Cabin (upper Wind River) age. Below it, near the base of the Wasatch, he also found *Homogalax* diagnostic of Granger's Gray Bull faunal zone.

The massive buff sandstone beds in the basal part of the Wasatch on North Fork are strikingly similar to the basal Wasatch beds on the South Fork in T. 51 N., R. 104 W. The massive buff sandstone beds on North Fork probably belong in the lower Wasatch unit but until further work is done their position can not be determined definitely. Likewise the Wasatch beds of Wind River age on North Fork are lithologically similar to the higher Wasatch strata on the South Fork in T. 51 N., R. 104 W. Thus, eventually it may be possible to demonstrate that the lower Wasatch unit is of Gray Bull age and per-

[27] G. L. Jepsen, "Dating Absaroka Volcanic Rocks by Vertebrate Fossils" (abstract), *Bull. Geol. Soc. America*, Vol. 50, No. 12, Pt. 2 (1939), p. 1914.

haps the correlative of Love's Indian Meadows formation,[28] and that the upper Wasatch unit is of Wind River age and possibly the correlative of Love's Wind River formation.

Volcanic rocks.—The Wasatch formation is overlain by rocks to which Hague[29] applied the name "early basic breccia." This breccia is predominantly agglomerate, volcanic conglomerate, and breccia. It is related to the structural features of the area because it borders or terminates the western sides of the two largest remnants of the Heart Mountain thrust, Sheep Mountain, and Logan Mountain. The "early breccia" is later than the Heart Mountain thrust and consequently overlies it, except at places where the breccia is intrusive—that is, where breccia-filled vents and fissures cut across the thrust.

In South Fork Valley several hundred feet of tuffaceous rocks occur between the Wasatch and typical beds of volcanic breccia. Hague included them as part of his "early basic breccia." Rouse,[30] in his study of the area in the vicinity of Valley Post Office, outside the southwest corner of the area shown in Figure 7, separated the tuffaceous rocks from the overlying volcanic breccias and applied to them the term "early basic tuffs." In a later paper he[30] returned to the original usage of Hague and included the "early basic tuffs" as a part of the "early basic breccia."

The lithologic character of the basal beds of Hague's "early basic breccia" changes greatly from northeast to southwest. At Sheep Mountain, breccia and agglomerate rest directly on limestone of the Heart Mountain thrust sheet; west of Sheep Mountain, where the limestones of this thrust sheet are absent, breccia rests on the Wasatch formation; west of Hardpan Creek, 150 feet of tuffaceous beds underlie the lowest volcanic breccia bed; and 6 miles farther southwest, about 400 feet of tuffaceous beds intervene between the Wasatch and the volcanic breccia. These tuffaceous beds are mapped as part of the "early basic breccia."

The "early basic breccia" rests unconformably on the underlying rocks. It was deposited upon an erosional surface, on which were scattered residual limestone blocks from the Heart Mountain overthrust sheet. On the East Fork of Twin Creek, for example, limestone

[28] J. D. Love, "Geology along the Southern Margin of the Absaroka Range, Wyoming," *Geol. Soc. America Spec. Paper 20* (1939).

[29] Arnold Hague, "Absaroka, Wyoming," *U. S. Geol. Survey Geol. Atlas Folio 52* (1899).

[30] J. T. Rouse, "The Volcanic Rocks of the Valley Area, Park County, Wyoming," *Trans. Amer. Geophys. Union*, 16th Ann. Meeting (1935), pp. 274–84.

———, "Genesis and Structural Relationships of the Absaroka Volcanic Rocks, Wyoming," *Bull. Geol. Soc. America*, Vol. 48, No. 9 (1937), pp. 1257–96.

blocks 1–4 feet in diameter occur at the unconformity between the Wasatch formation and the overlying tuffaceous beds of the "early basic breccia." Numerous other occurrences of limestone débris at the base of the "early basic breccia" could be cited.

Vertebrate fossils were found by Jepsen[31] in the tuffaceous beds in the lower part of the "early basic breccia" at a locality about 4 miles southwest of the southwest corner of the area covered by Figures 2 and 7. He reports that the fossils indicate Bridger or Lost Cabin age and suggests that the beds "are not older than late Early Eocene and may be of Middle Eocene age."

The material in the "early basic breccia" was erupted through numerous fissures and irregular-shaped vents within the area here described. In places the breccia makes a nearly vertical intrusive contact with limestones of the Heart Mountain thrust sheet, and seemingly envelops parts of the western edge of the Heart Mountain thrust sheet. Some of the localities where the thrust sheet is terminated by intruded breccia in large fissure vents are: on the west side of Rattlesnake Creek in the N. ½ T. 53 N., R. 104 W.; west of Trout Creek; along Post Creek; and west of the southern part of Sheep Mountain.

The intrusive bodies of breccia occupying the irregular-shaped vents commonly have a northwesterly alignment. One of the zones of structural weakness with such an alignment includes the Castle fault at its southeast end. In this zone in Post Creek Valley the breccia is thought to have come up along several northwest-trending fissures; to the northwest across the North Fork of the Shoshone River a fissure or dike of volcanic breccia has a similar northwesterly alignment (Fig. 7). A few hundred feet east of this dike is a much larger mass of northwesterly aligned breccia, which is probably intrusive also.

The extrusion of the volcanic breccia, as has been pointed out by M. M. Sheets, deformed to some extent the rocks that adjoin the breccia-filled vents. This deformation is confined to the closely adjoining parts of the country rock, and can be observed principally in the limestone and dolomite of the Heart Mountain thrust sheet. At most places it produced numerous faults, but in addition, movement of breccia raised or sharply tilted large blocks of limestone.

AGE OF THRUSTS

Age of Heart Mountain thrust.—The Heart Mountain thrust is younger than the fossil-bearing Wasatch beds in the northwestern part of T. 52 N., R. 104 W. As already described, those beds contain

[31] G. L. Jepsen, *op. cit.*

Wind River and Lost Cabin[32] vertebrate fossils, and are thus of late lower Eocene age. In terms of the provincial ages recently proposed by the Committee of the Vertebrate Section of the Paleontologic Society, they are of late Wasatchian[33] age.

A collection of vertebrate fossils was obtained by Hewett[34] at McCulloch Peaks, from a zone about 150 feet below the base of the Heart Mountain thrust. It was examined both by Gidley and Granger. Gidley's age assignment is summarized as follows: "It would thus seem that the three specimens represent a Bridger fauna, although the Eohippus tooth suggests Wasatch rather than Bridger affinities." Granger makes the following age assignment: "These three specimens seem to represent a fauna intermediate between that of the upper Wind River and that of Bridger B. It may belong to the base of the Bridger (Hor. A), the mammalian fauna of which is practically unknown, correlation with the upper Huerfano being made on a single specimen of Titanothere. In any event the McCulloch Peak horizon is close to the border line between the Lower and Middle Eocene." The McCulloch Peak collection has recently been examined by Horace E. Wood, 2d, who reports[35] that the age determination of early Bridger, as opposed to Lost Cabin, rests upon the identification of a specimen as *Helaletes* or as a *Helaletes*-like species of *Heptodon*. In his opinion there is a moderate balance of probability in favor of age equivalence to upper Wind River (Lost Cabin).

The closest upward confining limit of the age of the Heart Mountain thrust is fixed by the age of the "early basic breccia." As had already been discussed, this is reported by Jepsen as either "Bridger (Middle Eocene) or Lost Cabin (upper division of the Wind River late Early Eocene)."

Thus the youngest beds preceding the emplacement of the Heart Mountain thrust seem to be late lower Eocene. The oldest beds that were deposited after the emplacement of this thrust are either early middle Eocene or very late lower Eocene. The emplacement of the thrust in this area therefore took place near the close of the lower

[32] Lost Cabin is a geographic name that has been applied by vertebrate paleontologists to the *Lambdotherium* faunal zone, which forms the upper part of the Wind River formation.

[33] H. E. Wood, 2d, chairman, and others, "Nomenclature and Correlation of the North American Continental Tertiary," *Bull. Geol. Soc. America*, Vol. 52, No. 1 (1941), pp. 1–48.

[34] D. F. Hewett, "The Heart Mountain Overthrust, Wyoming," *Jour. Geology*, Vol. 28, No. 6 (1920), pp. 548–50.

[35] Personal communication.

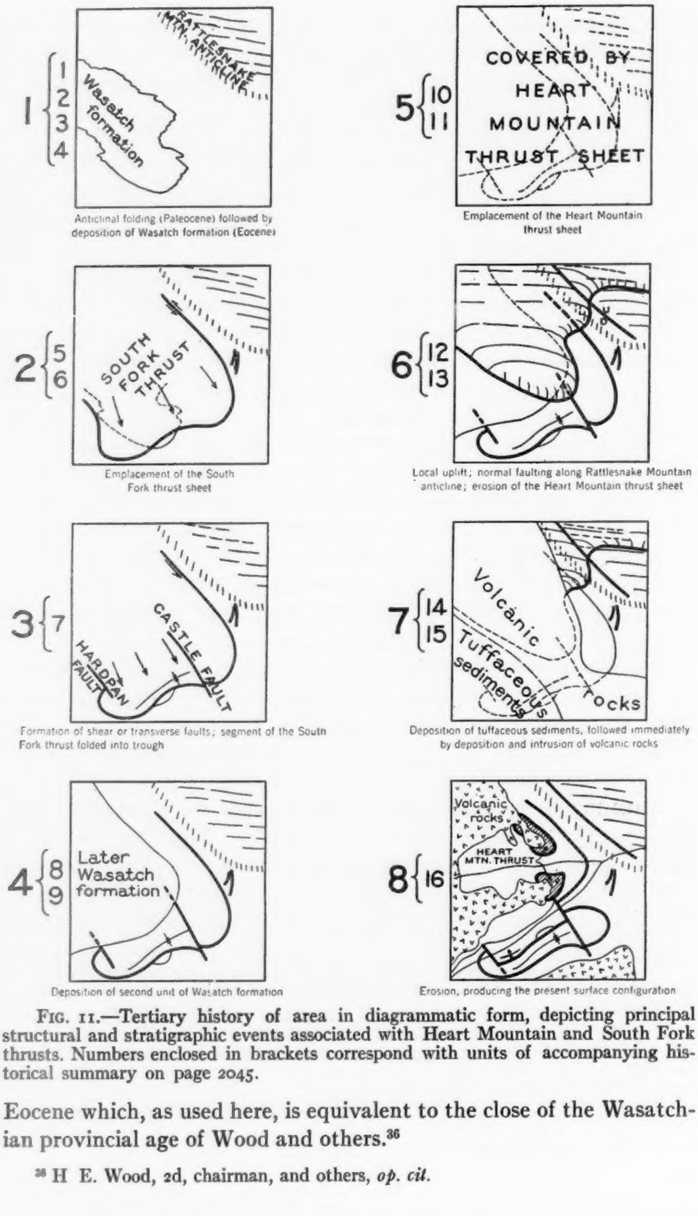


FIG. 11.—Tertiary history of area in diagrammatic form, depicting principal structural and stratigraphic events associated with Heart Mountain and South Fork thrusts. Numbers enclosed in brackets correspond with units of accompanying historical summary on page 2045.

Eocene which, as used here, is equivalent to the close of the Wasatchian provincial age of Wood and others.[36]

[36] H E. Wood, 2d, chairman, and others, *op. cit.*

Age of South Fork thrust.—The South Fork thrust is of lower Eocene age and is older than the Heart Mountain thrust. Closer age delimitation is dependent on the age determinations of the two units of the Wasatch which have already been mentioned in the discussion of the Wasatch formation. If the correlations suggested prove to be correct, then the South Fork thrust was emplaced between Gray Bull and Lost Cabin time.

TERTIARY STRUCTURAL AND STRATIGRAPHIC HISTORY

The principal structural and stratigraphic events associated with the Heart Mountain and South Fork thrusts are shown diagrammatically in Figure 11. The history of the area in outline form is as follows.

1. Deposition of Fort Union formation (Paleocene). No remnants of it remain west of Rattlesnake Mountain.
2. Folding of Rattlesnake Mountain anticline.
3. Erosion.
4. Deposition of Wasatch strata.
5. Small sill of igneous rock intruded into beds along Rattlesnake Creek.
6. Emplacement of the South Fork thrust.
7. Faulting and folding: formation of Castle and Hardpan faults; South Fork thrust folded into a trough.
8. Erosion.
9. Deposition of later Wasatch strata.
10. Erosion?
11. Emplacement of the Heart Mountain thrust sheet.
12. Uplift of the area to the southwest of Sheep Mountain and Trout Creek, or conversely, subsidence of the northeastern area. Normal faulting along Rattlesnake Mountain anticline.
13. Erosion, removing most of the Heart Mountain thrust sheet west of Sheep Mountain and Trout Creek.
14. Deposition of tuffaceous beds, followed immediately by deposition and intrusion of the "early basic breccia."
15. Early basalt flows; dike intrusions; deposition of late volcanic breccias and basalts.
16. Erosion, continuing to the present time; formation of stream terraces; deposition of glacial moraine in the southwest corner of the area.

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POST-APPALACHIAN FAULTING IN WESTERN KENTUCKY[1]

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ABSTRACT

The intricate faulting in the Mississippian and Pennsylvanian formations of western Kentucky has been usually correlated with the Appalachian orogeny. Post-Paleozoic sediments are all unconsolidated and evidence of post-Appalachian faulting is consequently obscure; references to the possibility of later faulting have heretofore been largely unsupported by specific evidence.

Detailed examination of the area establishes the occurrence of later faulting. Just as the epeirogenic disturbances in this region at the end of the Paleozoic era were associated with important faulting, the similar but less intense epeirogenic movements during the Cretaceous and Eocene periods led to renewed faulting—probably, however, on a smaller scale.

INTRODUCTION

The hard rocks of the Ohio, Tennessee, and the Cumberland River regions of western Kentucky, ranging in age from Devonian to Pennsylvanian, are complexly faulted. They are overlain by remnants of a formerly widespread and continuous mantle of Upper Cretaceous gravel, sand, and clay. These Cretaceous sediments, being unconsolidated, only rarely contain clearly observable evidences of having been faulted.

It has usually been assumed that the faulting occurred subsequent to the Pennsylvanian period and prior to the Cretaceous depositions, a correlation with the Appalachian disturbances being stated or implied in the literature. Writers have occasionally suggested the possibility or probability that the Upper Cretaceous sediments are also, at least locally, involved in the faulting, but specific references to field evidence supporting this opinion are rare.

Detailed geological studies, made in connection with the Kentucky Project of the Tennessee Valley Authority, have disclosed both direct and indirect evidences of Cretaceous or post-Cretaceous faulting. Interpretations of geologic conditions encountered during foundation studies at Kentucky Dam required a more precise elucidation of the region's post-Paleozoic development than had previously been made. Painstaking observation of rather obscure field evidence has led to the conclusion that this later faulting, while probably less intense than that associated with Appalachian disturbances, is basic to the consid-

[1] Read before the Tennessee Academy of Science, November, 1939. Manuscript received April 14, 1941. Released by the Tennessee Valley Authority.

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eration of the geologic history of the area. The following description of the field evidence indicative of later episodes of faulting is therefore presented with the conviction that recognition of Cretaceous and later faulting will be a necessary part of any definitive analysis of the structural, stratigraphic or physiographic relationships in western Kentucky.

GEOLOGIC CONDITIONS[4]

Extreme western Kentucky, situated in the area of the Mississippi Embayment, is covered with thick Tertiary and Cretaceous sediments which become progressively thinner toward the east, near the eastern margin of the embayment. The underlying Paleozoic floor of the embayment emerges from beneath these younger sediments in the vicinity of the Tennessee River, where the cover of Upper Cretaceous formations is discontinuous. A few miles farther east, near the Cumberland River, Paleozoic strata, or their weathered equivalents, are the principal surface formations, the Cretaceous sediments occurring only as widely separated outliers of a formerly more continuous mantle.

The area embraced in the following discussions includes the valleys of the Tennessee and Cumberland rivers, south from the Ohio River to the Tennessee State line. The region so defined is roughly the Kentucky portion of the belt of transition from the sediments of the Mississippi Embayment, west of the Tennessee River, to the predominant Paleozoic rocks, east of the Cumberland River. This belt is the only area in Kentucky conducive to surficial geological studies involving Cretaceous formations; west of the Tennessee Valley the Cretaceous sediments are concealed by terrace gravels and loess and east of the Cumberland River they occur very sparsely.

The Paleozoic formations which are exposed east of the Mississippi Embayment (east of the Tennessee River) are predominantly upper Mississippian, ranging in age from Osage to Chester. Pottsville sandstones of Pennsylvanian age, the youngest Paleozoic rocks of the region, occur in several localities, in most places bounded by faults.

The Upper Cretaceous sediments which occur in contact with the Paleozoic strata within and near the lower Tennessee Valley belong to the Tuscaloosa and Ripley formations, the Ripley overlying the Tuscaloosa uncomformably. The Tuscaloosa formation in this area consists entirely of coarse, very clayey gravel. The Ripley formation is predominantly fine sand, containing thin clay intercalations and persistent clay layers of greater thickness near the bottom. These two

[4] "Engineering Geology of the Tennessee River System," *Tennessee Valley Authority Tech. Mono. 47* (May, 1940). Chapter 2, "The Kentucky Project," by Roger Rhoades.

formations are only slightly consolidated: in most places both are slumped at the surface, undisturbed sections being observable only in road cuts, test pits, or other artificial excavations.

Terrace gravels of Pliocene (?), Pleistocene, and Recent age, also imperfectly consolidated, overlie the Cretaceous sediments in many places and the topography is blanketed with loess-loam.

There are no sediments representative of the Pottsville-Upper Cretaceous time-interval or of the Upper Cretaceous-Pliocene (?) time-interval in the immediate area under discussion although Eocene sediments occur farther west, between this area and the Mississippi River.

Faults transect all Paleozoic formations.[5] These faults are especially numerous in the counties adjacent to the Ohio River where they form an intricate mosaic pattern, with major lines of fracture continuing with great uniformity for many miles and displaying displacements which in some places exceed 1,000 feet. A profusion of cross-faults, possessing random orientations and smaller displacements, subdivide the major fault blocks. In nearly all cases, the fault planes are vertical or inclined only slightly from the vertical, their traces consequently forming straight or broadly arcuate lines. The faults are ordinarily obscured west of the Cumberland River by the unconsolidated post-Paleozoic formations beneath which the Paleozoic rocks are buried.

The faulting is known to be post-Pottsville. More specific dating of the faulting is hindered by the absence of strata representative of the Pottsville-Upper Cretaceous time-interval or, at most places east of the Cumberland River, of the interval between Pottsville and Recent time. Moreover, evidence of the involvement of Cretaceous formations in the faulting is inconspicuous. This obscurity has been responsible for the general opinion that the faulting, known to be post-Pottsville and thought to be pre-Upper Cretaceous, is most probably correlative with the Appalachian disturbances.

HISTORICAL BACKGROUND

References to the possibility of Cretaceous or later faulting appear in geologic literature but they are neither specific nor conclusive. Jillson[6] expressed the opinion that some Cretaceous sediments had

[5] The following maps are published by the Kentucky Geological Survey: Geological Map of Kentucky; geological maps of Dawson Springs, Cave-in-Rock, and Smithland, (unpublished) quadrangles; and geological maps of Trigg, Lyon, and Livingston counties, Kentucky. The county maps noted are of reconnaissance character, and the state map is considerably generalized.

[6] W. R. Jillson, "The Geology and Mineral Resources of Kentucky," *Kentucky Geol. Survey*, Ser. VI, Vol. 17 (1928), p. 48.

been faulted in western Kentucky without, however, citing any observed occurrences. The geological map of Lyon County and the geological map of the state of Kentucky, both prepared by the Kentucky State Geological Survey under the direction of Jillson, indicate that the Oakland fault traverses the Tuscaloosa gravels but no published references concerning this fault are available. Jillson[7] also expressed the belief that some of the fault lines traversing the Paleozoic basement rocks of Fulton and Hickman counties are still lines of active movement.

Roberts[8] discussed the possibility that Cretaceous sediments had been faulted in Trigg County, Kentucky, and mentioned two suggestive localities: (1) he described the juxtaposition of Cretaceous and Mississippian formations and an alignment of springs near Ferguson Springs and (2) mentioned that, in a road-side pit on the north side of the Jefferson Davis Highway (Highway 68), the Tuscaloosa gravels possess a steep dip. In an earlier publication Roberts[9] states that faults cannot be located in the Tuscaloosa formation and follows Dunbar[10] in excepting the Tuscaloosa from the faulting activity and in assigning this activity to a period contemporaneous with the Appalachian revolution. However, he expressed belief that "Monoclinal folding . . . associated with withdrawal of the Midway (Eocene) sea was accompanied by faulting along old fault lines"[11] and stated that, "The age of the faulting is certainly pre-Cretaceous but very likely gravels have suffered some displacement by growth along these old fault planes, and by settling in the process of consolidation."[12]

Weller,[13] in describing the geology of the Cave-In-Rock Quadrangle, notes that the youngest Pennsylvanian beds of the area are faulted and that faulting in the Cretaceous sediments is not recognizable. He associates the faulting and the intrusion of the basic igneous dikes of the area with the Appalachian orogeny but recognized that "readjustments" probably have continued to the present time.

Sutton, in his discussion of the geology of the Smithland (Ken-

[7] *Ibid.*, p. 120.

[8] J. K. Roberts, "The Cretaceous Deposits of Trigg, Lyon, and Livingston Counties, Kentucky," *Kentucky Geol. Survey*, Ser. VI, Vol. 31 (1929), pp. 307–08, 298–99.

[9] J. K. Roberts, "Tuscaloosa Formation of Western Kentucky," *Jour. Geology*, Vol. 14 (1927), pp. 469–70.

[10] Carl O. Dunbar, "Stratigraphy and Correlation of the Devonian of Western Tennessee," *Tennessee Geol. Survey Bull. 21* (1919), p. 15.

[11] J. K. Roberts, *op. cit.*, p. 470.

[12] *Ibid.*

[13] Stuart Weller, "Geology of the Cave-In-Rock Quadrangle," *Kentucky Geol. Survey*, Ser. VI, Vol. 26 (1926), p. 91.

tucky) Quadrangle,[14] asserts the probability that the major faulting of the area was post-Pennsylvanian and pre-Upper Cretaceous and elsewhere[15] concludes that the recent tectonic activity of the region (emphasizing the earthquake of 1811–1812) was an expression of minor movements which have recurred at intervals since the major faulting which closed the Paleozoic era in this region. In a later publication[16]

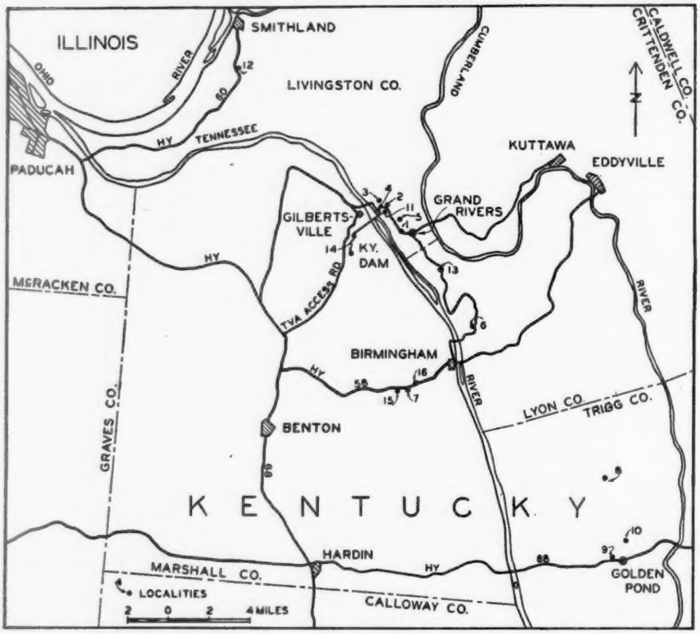

FIG. 1

Sutton cites the occurrence of a pre-Cretaceous soil horizon whose relationships led him to the belief that the faulting occurred a long time prior to the deposition of Cretaceous sediments.

All of the authors previously mentioned have emphasized that the unconsolidated nature of the Cretaceous sediments would lead to quick obliteration of clearly observable evidences of their structure.

[14] A. H. Sutton, "Geology of the Smithland Quadrangle, Kentucky." Unpublished manuscript.

[15] *Idem*, "Geology of the Southern Part of Dawson Springs Quadrangle, Kentucky," *Kentucky Geol. Survey*, Ser. VI, Vol. 31 (1929), p. 266.

[16] *Idem*, "A Pre-Cretaceous Soil Horizon in Western Kentucky," *Amer. Jour. Sci.*, Vol. 22 (1931), pp. 449–52.

LOCALITIES EXHIBITING EVIDENCES OF LATER FAULTING

Localities contributing field evidence substantiating the occurrence of later faulting are described in the following paragraphs. These localities are divided, as indicated by the following sub-headings, into various categories indicative of the different kinds of evidence which they exhibit. The localities cited are indicated by number on the locality map (Fig. 1).

Observable Faults

In localities at which faults are directly observable, the Ripley and Tuscaloosa formations appear in fault contact or, as in locality No. 2, a fault is discernible within the Tuscaloosa formation. It must be emphasized that the slumping of these unconsolidated formations obscures the relationships on all but fresh, artificial excavations; this fact probably is mainly responsible for the small number of clearly observable fault localities.

Locality No. 1—Grand Rivers fault.—This fault is exposed in the sand and gravel bank opposite the turn in the Grand Rivers-Gilbertsville road, ½ mile west of Grand Rivers Post Office. Red Ripley sand is in abrupt contact with white Tuscaloosa clay. A 14-inch layer of loosely cemented gravel within the Ripley is tilted by drag and nearly parallels the outcrop of the fault plane, and is folded backward into an overturn at the top of the bluff. The contact between these two formations is a fault plane which dips 40° SE. in the lower part of the exposure, steepening nearly to verticality at the top. The bearing of the fault is approximately N. 60° E. but the loess-loam mantle obscures the precise direction.

Locality No. 2—gravel pit fault No. 1.—A fault cuts a 20-foot bank of Tuscaloosa gravel 200 yards northeast of the Gilbertsville-Grand Rivers road, at the northeast end of the Illinois Central Railroad gravel pit, approximately in line with Kentucky Dam. The fault plane is nearly vertical and has an approximate bearing of N. 18° E. In one exposed vertical section, slickensides are observable. The fault trace may be followed 50–60 feet on either side of this exposure. Although the fault plane is bounded on both sides by Tuscalossa gravels, the low elevation of red Ripley sand immediately east of the fault indicates that the east side is the downthrown section.

Locality No. 3—gravel pit fault No. 2.—In the north end of the gravel pit behind the east abutment of Kentucky Dam, 100 yards northwest of locality No. 2, the Tusculoosa and Ripley formations are in contact along a fault plane which is essentially vertical and strikes N. 60° E. The red and yellow sands and the yellow and gray clays of the Ripley formation in this area have very variable dips, usually quite steep, which, near the fault, approach verticality; in a few places along the contact the beds are overturned. Structural relationships in this area are complicated, dips and strikes becoming more variable and contortion of the Ripley sands and clays more pronounced near the fault.

The Tuscaloosa formation to the southeast of the fault is immediately underlain by Mississippian (Warsaw) residual chert. The Ripley formation lies on the northwest. Thus a displacement amounting to most of the thickness of the Tuscaloosa formation is indicated; the formation is over 110 feet thick in other parts of this gravel pit.

PROBABLE FAULT OUTCROPS

The following localities exhibit relationships between the Tuscaloosa and Ripley formations and residual chert and clay (Mississippian) which are strongly—frequently almost conclusively—suggestive

of faulting but are sufficiently obscure because of slumping to introduce some uncertainty of interpretation.

Locality No. 4—temporary railroad cut, Kentucky Dam.—In the temporary railroad cut behind the east abutment of Kentucky Dam, three exposures exhibit Tuscaloosa-residual chert (Mississippian) contacts along planes which are steep (up to 70°) and sharp. The most continuous and clearly observable contact plane strikes N. 26° E. These contact planes are probably faults.

Locality No. 5—Glynn gravel pit, Livingston County.—A Tuscaloosa-Ripley contact which is probably a fault is exposed in the northeast corner of the Glynn gravel pit (reached by turning to the northeast along an unimproved road which leaves the Grand Rivers-Gilbertsville road, 1.5 miles from Grand Rivers Post Office). Red sand with streaks and lenses of white sand (Ripley formation) is in contact with white Tuscaloosa gravel. The contact plane dips 46° SE. and strikes approximately N. 50° E. The Tuscaloosa on the north side of the probable fault dips 20° toward the fault. This dip flattens to 7° 100 yards farther north, the latter dip persisting across the main working face of the gravel pit. A 2-foot zone of siliceously cemented gravels adjoins the fault contact and a similarly cemented gravel is intermittently traceable for 200 yards northeast of the exposed fault plane, probably outlining the fault trace.

Locality No. 6—Star Lime Works, Lyon County.—On the north side of the road in a cut 0.3 miles upstream from Star Lime Works, Kentucky, where the road turns sharply west after crossing a creek ford, Ripley sand is level with, and adjacent to, Mississippian residual chert and clay (Warsaw). From east to west, the 10-foot vertical bank exhibits residual chert in abrupt contact with a confused zone containing sandy brown clay, small rounded gravel, and angular chert blocks. This jumbled zone, 15 feet wide, abuts sharply against unconsolidated red Ripley sand which continues laterally for 16 feet and blends into a zone of sandy, red and gray clay (Ripley) containing numerous thin irregular ironstone layers. Several small clay dikes penetrate the 15-foot jumbled zone. These dikes are thin (up to 2 inches wide), and contain hard red clay.

Locality No. 7—Birmingham Road (Highway 58), Marshall County.—A road cut on Highway 58, 7.7 miles east of the junction of highways 58 and 68 exhibits a complicated zone of steeply dipping sands and clays of the Ripley formation. From west to east, dove-gray clay, dipping 40° westward, is underlain by a gray-green clay which contains lenses and stringers of yellowish sandy clay. The gray-green clay is brought to the surface by the dip which suddenly steepens to 60° as the gray-green clay abuts against an orange sand. The contact plane dips 65° SW. and strikes N. 35° W. An observable displacement of several feet is suggestive of faulting.

Locality No. 8—Ferguson Springs, Trigg County.—The locality described by Roberts[17] between Energy and Ferguson Springs, Kentucky, exhibits Mississippian limestone on the east side of Crooked Creek and Tuscaloosa gravels on the west at the same topographic level. The Tuscaloosa-Mississippian contact is not exposed in the area but Crooked Creek seems to follow the probable fault trace to the north as far as Ferguson Springs.

Locality No. 9—Golden Pond, Trigg County.—Roberts[18] described a roadside gravel pit west of Golden Pond, on the north side of the Jefferson Davis Highway (Highway 68) which exhibits about 20 feet of Tuscaloosa gravel (this locality is 0.6 miles west of the schoolhouse standing at the west edge of the town of Golden Pond). Bedding planes in this pit, although rather obscure, indicate a westward dip of 19°. The strike is slightly east of north.

ABRUPT THICKENING OF CRETACEOUS FORMATIONS

The Tuscaloosa formation normally occurs as a comparatively thin blanket on the ridge between the Tennessee and Cumberland rivers. Locally, as at localities noted in the following paragraphs, the Tuscaloosa formation is much thicker, forming the entire body of the ridge

[17] J. K. Roberts, "The Cretaceous Deposits of Trigg, Lyon, and Livingston Counties, Kentucky," *Kentucky Geol. Survey*, Ser. VI, Vol. 31 (1929), p. 307.

[18] *Ibid.*, p. 298.

and in some places extending down to the edge of the Tennessee River flood plain. Although the boundaries of these thick accumulations are nowhere observable, the zones of transition between the thick and thin portions of the formation are not wide and are probably sharp.

These relationships are harmonious with physiographic interpretations of the area which suggest that original Tuscaloosa deposition was associated with grabens which sank progressively as deposition proceeded. The Tuscaloosa sea encroached upon a terrane of low relief which was covered with a thick regolith of residual chert and clay.[19] The thicker parts of the Tuscaloosa were deposited in sinking troughs, bounded by faults.[20]

Locality No. 10—Golden Pond, Trigg County.—The Tuscaloosa gravels and the underlying residual chert in the highlands east of the Tennessee River in the vicinity of Golden Pond, Kentucky, are both abnormally thick, in contrast to the comparatively thin coverings on the ridge-tops farther north and south. Roberts[21] recorded a thickness of the Tuscaloosa formation of 170 feet in this area and an oil well drilled a short distance west of Golden Pond is reported to have penetrated several hundred feet of that formation, although this figure probably includes the underlying residual chert which, in the form of drill-cuttings, is scarcely distinguishable from the Tuscaloosa gravel.

Exploratory borings in the Tennessee River at the Aurora Dam site, immediately west of this area, indicated that the residual chert was more than 300 feet thick, extending downward to elevation 47 feet above sea-level.[22]

Locality No. 11—Gilbertsville area, Livingston County.—The Tuscaloosa formation is abnormally thick in an area to the east of the Tennessee River, between the towns of Gilbertsville and Grand Rivers. Roberts[23] noted that the Tuscaloosa formation in this area is 110 feet thick and subsequent drilling at Kentucky Dam site indicates that this thickness is locally exceeded. The Tuscaloosa formation is underlain by unusual thicknesses of Mississippian (Ft. Payne and Warsaw) residual chert.

The southern boundary of this area, near the town of Grand Rivers, is the Grand Rivers Fault (Locality No. 1).

ABRUPT TRANSITION BETWEEN CRETACEOUS AND MISSISSIPPIAN FORMATIONS

At the localities noted in the following paragraphs, Cretaceous formations abut sharply against Paleozoic formations. Deposition in valleys eroded into the Mississippian formations would give similar contact relationships, but the preponderance of existing evidence favors the deposition of the Cretaceous sediments on a terrane of very slight relief, suggesting that the contacts in question are faults.

Locality No. 12—Mantz School, Livingston County.—The Ripley formation abuts with abrupt transition against the St. Louis formation (Mississippian) and the Casey-

[19] Roger Rhoades, "Relation of the Tuscaloosa Formation of Western Kentucky to a Pre-Existing Weathered Terrain," *Bull. Geol. Soc. America,* Vol. 51, No. 12, Pt. 2 (December 1, 1940), p. 1940.

[20] *Idem,* "Hypothesis for the Explanation of the Deep Rock Decomposition in the Lower Tennessee Valley," oral presentation, Tennessee Academy of Science, November, 1939.

[21] J. K. Roberts, "The Cretaceous Deposits of Trigg, Lyon, and Livingston Counties, Kentucky," *Kentucky Geol. Survey,* Ser. VI, Vol. 31 (1929), pp. 298–99.

[22] Roger Rhoades, *op. cit.*

[23] J. K. Roberts, *op. cit.*, pp. 299–313.

ville formation (Pennsylvanian) in the vicinity of Mantz School, south of Smithland.[24]

The Ripley formation covers the ridges east of Highway 60, rising to 500 feet above sea-level. It is well exposed in roadcuts where the highway turns northwest at the school and heads down a draw toward Smithland. Near the bottom of the draw, the Ripley has descended to approximately 375 feet above sea-level and terminates abruptly against a major northeast-southwest trending fault beyond which the exposed rocks are Mississippian and Pennsylvanian in age.

A small outlier of Tuscaloosa gravel (which normally underlies the Ripley formation) occurs on the top of a small knoll on the northwest side of the fault at 500 feet above sea-level—125 feet above the Ripley on the other side of the fault.

This exposure indicates either: (1) post-Ripley faulting, (2) the formation of a post-Tuscaloosa fault basin in which the Ripley was deposited or (3) post-Tuscaloosa erosion of a steep-walled valley, at least 125 feet deep, in which the Ripley was deposited. The first two possibilities imply Cretaceous or post-Cretaceous faulting. The third possibility is probably untenable in view of the absence of evidence of any such degree of post-Tuscaloosa and pre-Ripley erosion in the area.

The fault in question is one of the major lines of displacement of the area, exhibiting stratigraphic displacements of about 1,000 feet. It is probable that the implied Cretaceous or post-Cretaceous movements were expressions of renewed activity along the line of more ancient faulting.

Locality No. 13—Grand Rivers—Star Lime Works, Lyon County.—On the old road which follows the Tennessee-Cumberland River divide, 2.8 miles upstream from Grand Rivers Post Office, the Ripley formation lies level with and adjacent to Mississippian residual chert and clay. The Ripley consists of 12 feet of red unconsolidated sand, containing a 3-inch ironstone layer. The Ripley is underlain by a 2-foot bed of very dense and hard, siliceously cemented conglomerate, containing both angular and rounded pebbles in a chert-like matrix. These beds are conformable, striking N. 65° E. and dipping 14° N. (toward the residual chert). Closely similar relationships are observable in the more recent road cut ¼ mile northeast, but the actual Ripley-residual chert (Mississippian) contact is not exposed at either place.

SAND AND CLAY DIKES

At the following localities Cretaceous and later formations exhibit sand and clay dikes indicative of earthquake vibration (see also locality No. 6). These dikes do not necessarily indicate faults in the immediate vicinity but they do indicate the continuation of tectonic activity subsequent to the deposition of post-Paleozoic formations. This continued tectonic activity is in part post-Pliocene (?) and pre-Pleistocene (affecting the older but not the younger terrace gravels) and may indicate early developments of the present-day seismic activity of the region. Sand dikes up to 18 inches in width were reported by Roberts[25] in the Porter's Creek (Eocene) clay of both Tennessee and Kentucky. Glenn[26] reports sand and clay dikes in Tertiary formations of West Kentucky.

Locality No. 14—test pits, west abutment of Kentucky Dam, Marshall County.—Two test pits on the ridge which forms the west abutment of Kentucky Dam, one 5,800 feet west of the Tennessee River and the other 9,240 feet west of the river, exhibit gravel and

[24] A. H. Sutton, "Geology of the Smithland Quadrangle, Kentucky." Unpublished manuscript.

[25] J. K. Roberts, "Tertiary Deposits of Western Kentucky," *Kentucky Geol. Survey*, Ser. VI, Vol. 41 (1931), pp. 256–60.

[26] L. C. Glenn, personal communication.

clay dikes. The dikes traverse terrace gravels of Pliocene (?) age and sands and clays of the Ripley formation. The dikes vary in width from about 3 feet as a maximum down to thin stringers a fraction of an inch across. Material intruded to form the dikes has come variously from above and from beneath. The attitudes of the dikes are nearly vertical in most places. They possess sharp boundaries, but in some places they exhibit pronounced and complicated distortion and irregular offshoots. Regardless of attitude, the dikes display remarkable continuity, extending through different materials without interruption.

Locality No. 15—Fred Pitt gravel pit, Marshall County.—A gravel pit on the Birmingham Road (Highway 58) 6.9 miles from the junction of highways 58 and 68 exhibits numerous sand and clay dikes. One large dike, 9½ feet wide, is filled with red sand which probably was intruded from below. The numerous smaller dikes, 1–8 inches wide, are filled with either bluish gray, soapy clay, or red clay, from beneath, and fine chert gravel of uncertain source. The dikes are, in most places, vertical but some are inclined as much as 45° and have numerous offshoots. These dikes traverse Pliocene (?) terrace gravels, but in this exposure terminate at the top against a 1-foot layer of younger terrace gravel which immediately underlies the soil mantle. One 6-inch dike, slickensided on both walls, has a bearing N. 45° E. Vertical planes 2–3 inches wide indicate movement in the terrace gravel; the gravels are standing vertically along these planes and the adjacent bedding is offset. There are three such zones, each with observable displacement of about one foot.

Locality No. 16—Birmingham Road (Highway 58), Marshall County.—On Highway 58, 8.2 miles from the junction of highways 58 and 68, a road-cut exhibits a complication of relationships within the Ripley formation and between the Ripley and overlying Pliocene (?) terrace gravels. On the south side of the road, a coarse gravel bed, containing an exceptionally large number of quartz pebbles and unconformable with the underlying Ripley, appears to have a displacement of about 4 feet. These beds dip 15° NE. and strike N. 35° W. This disturbed area contains numerous small clay-filled dikes up to 4 inches wide. A prominent clay-filled dike (3–6 inches wide) is exposed on the north side of the road. The dikes are filled with red sandy clay with a few streaks of gray soapy clay, are vertical in most places, and in some places have numerous smaller offshots. The dikes traverse both the Ripley sands and the Pliocene (?) terrace gravels.

CONCLUSIONS

The widespread crustal activity associated with the Appalachian orogeny doubtless was accompanied by faulting within mid-continental areas, including western Kentucky. Detailed studies within and near the lower Tennessee Valley indicate that later displacements affected Upper Cretaceous and younger sediments in many places, the effects and evidences of the movements being inconspicuous mainly because of the incoherent lithologic character of these formations.

The paucity of field evidence of faulting in the post-Paleozoic formations cannot be wholly the result of imperfect preservation in these unconsolidated sediments; it is therefore probable that the pre-Cretaceous faulting was most intense, the later movements being fewer, and smaller in displacement.

The land movements at the close of the Paleozoic era were mainly epeirogenic within this part of the continental interior, bringing about the final withdrawal of the Paleozoic sea by uplift of the land. The early movements of this period were of a magnitude which has not subsequently been equaled in this area, and the associated faulting was doubtless more intense than at any later time. But a renewed

invasion of the sea occurred on a smaller scale during the Upper Cretaceous period, epeirogenic movements causing the intermittent development of the Mississippi Embayment which received Cretaceous and Tertiary sediments. Faulting also occurred during this period of crustal instability—beginning just prior to the time of Tuscaloosa deposition and continuing until the sea was again expelled from the continent's interior, following the deposition of the observable Eocene deposits. The smaller magnitude and number of the faults of this later period of earth movement undoubtedly was the reflection of the lesser intensity of these later epeirogenic disturbances.

The direct field evidences point to faults which were post-Tuscaloosa but the faulting probably was inaugurated just prior to the time of Tuscaloosa deposition, when the first earth movements preliminary to the formation of the Mississippi Embayment were inaugurated. In substantiation of this belief, physiographic considerations which are too detailed for inclusion in the present discussion strongly suggest that the Tuscaloosa gravels were deposited on a newly faulted terrane.

Whether or not faulting recurred throughout the long period represented by the Pennsylvanian-Upper Cretaceous hiatus can not be determined.

The seismic activity in recent time within the middle Mississippi Valley indicates a continued or renewed crustal activity within this region. It is probable that although faulting was most intense and frequent during the two periods of pronounced epeirogenic activity, it was by no means restricted to them but recurred frequently.

Some of the later displacements may have occurred along pre-existing fault lines. It is possible that entirely new lines of movement also developed. The prevalent soil mantle and unconsolidated character of all post-Paleozoic formations combine to obscure the evidence bearing upon this phase of the problem.

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GEOLOGICAL NOTES

CLODINE FIELD, FORT BEND COUNTY, TEXAS[1]

JACK O. COLLE[2]
Houston, Texas

In June, 1941, the Clodine field was opened with the completion of the Providence Oil Company's Eva Hatfield well No. 1. The field is in the eastern part of Fort Bend County, approximately 2¼ miles west of the town of Clodine and 19 miles west of Houston. The field is traversed by the east-west San Antonio and Arkansas Pass Railroad. The Clodine area has long been considered a prospect and has been explored numerous times by various geophysical methods. In 1929 and 1930 the Gulf Oil Corporation drilled two tests, which were abandoned as dry holes at depths of less than 6,500 feet. These tests were located approximately one mile south and southwest of the discovery well. Since 1930, several deep dry holes have been drilled, some of which had sufficient oil and gas showings to warrant drill-stem testing.

The Providence Oil Company's Eva Hatfield No. 1, the discovery well, located 1,823 feet from the north line and 2,640 feet from the west line of the H. D. Brown Survey, was completed on June 19, 1941. The test was drilled to a total depth of 8,090 feet, and 5½-inch casing was cemented at 7,584 feet. The casing was perforated from 7,499 to 7,502 feet with ten holes. On a 24-hour production test through $\frac{3}{16}$-inch choke, the well flowed 187 barrels of 51° gravity distillate, with 950 pounds of pressure on the tubing and 2,350 pounds on the casing. The gas-oil ratio was 10,000 to 1. The top of the producing sand, which is a member of the Yegua formation, was determined according to the electrical log at 7,470 feet (sub-sea 7,364 feet). Sidewall cores showed the sand to be medium coarse-grained, firm, very porous, and grayish brown in color.

The subsurface paleontological contacts encountered in this well are as follows.

	Depths in Feet	
	Below Surface	*Below Sea-Level*
"Oligocene" *Discorbis*	3,619	3,513
"Oligocene" *Heterostegina*	3,739	3,633
Oligocene-Vicksburg-*Textularia warreni*	5,454	5,348
Eocene-Jackson-*Marginulina cocoaensis*	5,968	5,862
Eocene-Cockfield-*Nonionella cockfieldensis*	7,080	6,974
Eocene-Yegua-*Eponides yeguaensis*	7,319	7,213
Eocene-Cook Mountain-*Ceratobulimina eximia*	7,934	7,828

[1] Manuscript received, September 29, 1941.

[2] Geologist and paleontologist with Hershal C. Ferguson, consultant.

To date, two other producers and one dry hole have been completed. The Houston Oil Company's Thompson No. 1, $\frac{1}{2}$ mile north of the discovery well, was completed as a gas-distillate well. The top of the producing sand was at 7,459 feet (sub-sea 7,350 feet), 11 feet higher than the sand in the discovery well. The sand showed a thinning of approximately 15 feet. The Providence Oil Company's Wing No. 1, $\frac{3}{4}$ mile slightly north of east from Hatfield No. 1, was completed as an oil well, flowing 608 barrels per day of 42.2° gravity oil. The top of the sand was 10 feet lower than that in the Hatfield No. 1 and showed a thinning of 35 feet. The Houston Oil Company abandoned its Blakely-Nelms well No. 1 as a dry hole at the total depth of 7,594 feet. This well, $\frac{1}{2}$ mile west of the Hatfield well No. 1, failed to show any sand in the producing section.

From correlations of electrical logs, the Blakely-Nelms well No. 1 appeared to be high enough structurally to produce. Since the well did not have any sand, and evidence of faulting is lacking, it is the writer's opinion that the producing sand is lenticular. This lenticularity is further shown in the Wing well No. 1 which logged only 30 feet of sand as compared with 65 feet in the Hatfield well No. 1, and 50 feet in the Thompson No. 1. Sand lenses are common in the Yegua formation.

At present, sufficient information is lacking to determine definitely the type of structure. There is some evidence, however, of a northeast-southwest regional fault north of the field.

At this writing, no definite spacing rule has been decided upon. The Providence Oil Company and the Houston Oil Company hold most of the leases.

Credit for the discovery should be given to geophysics.

NON-MARINE ORIGIN OF PETROLEUM IN NORTH SHENSI, AND THE CRETACEOUS OF SZECHUAN, CHINA[1]

C. H. PAN[2]
Lawrence, Kansas

INTRODUCTION

Inasmuch as almost all the petroleum of the world comes from marine beds, most geologists believe that all petroleum must be of

[1] Manuscript received, August 15, 1941.

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marine origin. They generally do not believe that oil can originate from fresh-water sediments, and they generally believe that even if oil could originate from fresh-water sediments, it would not be in commercial quantities. Nightingale[3] recently published a very interesting paper on the non-marine origin of the oil of Powder Wash field in northwest Colorado. This field is reported to have a daily production of 1,000 barrels.

Oil that has been discovered in North Shensi province, China, is undoubtedly of non-marine origin. Also the oil obtained from Cretaceous beds in Szechuan probably comes from the Tzuliuching limestone, which is generally regarded as being of fresh-water origin.

NORTH SHENSI

STRATIGRAPHY[4]

Shihchienfên series.—Along the border between Shansi and Shensi provinces, the Shihchienfên series is exposed in a belt extending north and south. This series consists of purple-red sandstones and shales about 600 meters thick. It has been generally regarded as Permo-Triassic in age, but recently Bexell[5] has discovered representatives of the Angara flora (Permian) in corresponding redbeds of Kansu. Therefore, the Shihchienfên series is probably Permian in age.

Shensi series.—Next above the Shihchienfên series are deposits that have been classed by Fuller and Clapp under the name Shensi series.[6] This series is widely distributed in North Shensi, and covers almost the whole area. It may be divided into two parts. The lower is called the Yenchang formation, and the upper, the Wayaopu coal-bearing beds.

The Yenchang formation is equivalent approximately to what Fuller and Clapp termed the Yenchang phase. It occurs in the east part of North Shensi province, and consists of hard, gray cross-bedded sandstones and shales. Land plant fossils are abundant, and a few pelecypods and fish scales, seemingly non-marine, have been discovered at some horizons in this formation. There are no work-

[3] W. T. Nightingale, "Petroleum and Natural Gas in Non-Marine Sediments of Powder Wash Field in Northwest Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 8 (August, 1938), pp. 1020–47.

[4] C. C. Wang and C. H. Pan, "On the Oil Geology of North Shensi," *Geol. Survey China Bull. 22* (1933). C. H. Pan, "The Oil Shale Deposit of Northern Shensi," *ibid.*, *Bull. 24* (1934).

[5] G. Bexell, "On the Late Paleozoic and Mesozoic Plant-Bearing Beds of Nanshan, Kansu," *Geografiska Annaler*, Sven Hedin (1935).

[6] M. L. Fuller and F. G. Clapp, "Oil Prospects in Northeastern China," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 11 (November, 1926), pp. 1073–1117.

able coal beds. The thickness of the formation is about 1,270 meters. The Yenchang formation is correlated with the Keuper (Upper Triassic) of Europe.[7]

Wayaopu coal-bearing beds conformably overlie the Yenchang formation, and no definite line of demarcation separates them. In the lower part of the Wayaopu succession are four workable coal seams, which range in thickness from 0.4 to 1 meter. Strata associated with the coals consist of gray cross-bedded sandstones and gray and black shales like those of the Yenchang formation, and they contain land plant fossils. The middle part of these beds contains fish remains and deposits of oil shale. The Wayaopu coal-bearing beds have a total thickness of 850 meters. It is classed as Rhaetic and Lias.

Anting formation.—Conformably above the Wayaopu beds is the Anting formation, about 80 meters thick. It crops out along the border between North Shensi and Kansu, forming a narrow belt trending north and south. The lower part consists of red sandstones and shales, and the upper part of thin-bedded argillaceous limestone containing fish fossils, which have been determined by A. S. Woodward as *Pholidophorus*. The formation is Upper Jurassic in age.

Paoan series.—The western part of North Shensi and the eastern part of Kansu contain outcrops of the next younger rocks which are called the Paoan series. It consists of deep red sandstones and shales, and attains a thickness of about 2,000 meters. Its age is Cretaceous.

Reddish clay and loess.—Although the North Shensi basin is filled with Mesozoic sediments, the surface is mantled by reddish clay and loess. Its age ranges from upper Pliocene to Pleistocene.

STRUCTURE

North Shensi is mainly a basin in structure. East of the basin, in the west part of Shansi, and in the south border of the basin, between the Ichun and Tungkuan districts, steeply dipping Permo-Carboniferous coal series and Cambro-Ordovician limestones crop out. Within the basin the rocks consist of cross-bedded sandstones and shales which belong to the Shensi series. The strata lie nearly flat with a regional dip of 1°–3° W. or NW. There is no strong folding or faulting.

OIL SEEPAGES AND OIL SANDS

Oil seepages are widely distributed in North Shensi, but concentrated in the vicinity of Yenchang, Yungping (Yenchuan), Fushih, Chungpu, and Ichun. All the seepages are very small. A study of the

[7] C. H. Pan, "Older Mesozoic Plants from North Shensi," *Palaeontologia Sinica*, Ser. A, Vol. IV, Fasc. 2 (1936).

distribution of these oil seeps, together with the study of well logs from this area, leads to the conclusion that the oil probably seeps from eight different horizons. Five of these oil sands are in the Yenchang formation, and three are in the Wayaopu coal-bearing beds. In most places there is only a showing of oil of no commercial value.

SOURCE BEDS

The source beds of the oil of North Shensi are still unknown. Inasmuch as no intense folding or faulting is observed, it is best to assume that the oil of the oil sands comes from different source beds, which may be black or grayish blue shales near the oil sands. The source organisms are probably fishes, pelecypods, and plants. In the vicinity of Changchiatan, about 17 miles east of Yenchang, black shale containing fish scales has been discovered. This black shale is probably one of the source beds. There is no reason to believe that the oil comes from the Permo-Carboniferous and Cambro-Ordovician marine beds, because these beds are too deep, and we can not believe that oil could migrate from these deep marine beds through 600 meters of red sandstones and shales belonging to Shihchienfên series, which is barren. Furthermore, the Permo-Carboniferous and Cambro-Ordovician beds are not known to produce oil in the other parts of China.

OIL PRODUCTION

About 20 wells were drilled in North Shensi, but most of them only struck a showing of oil, and the rest of the holes were dry. The first oil well of Yenchang has had a daily production of about 0.3 barrel of oil for more than 20 years. The first oil well drilled by Mr. Pao in 1926 had an initial production of about 34 barrels a day, but it soon decreased to 1 barrel of oil a day. In 1932, this well produced only 0.3 barrel daily. In the years of 1934 and 1935, several more wells were drilled by the Resources Committee. No. 101, outside of the west gate of Yenchang, had an initial production of about 10 barrels, but it soon decreased to 1 barrel of oil per day. No. 201, east of Yungping, had an initial production of 20 barrels of oil per day, but after a half year it decreased to a daily production of about 1.6 barrels of oil.

GEOLOGIC CONDITIONS DURING THE DEPOSITION OF SHENSI SERIES

North Shensi has a basinal structure. It is therefore easy to imagine that North Shensi was gradually sinking during the deposition of the Shensi series, the rim of the basin being gradually uplifted at this time. About 2,000 meters of Shensi rocks were deposited in this basin. Continental origin of most, if not all, of the deposits is indicated

by the presence of abundant fossil land plants and coal beds. But at times the sediments in North Shensi were deposited in water, because fish and pelecypod fossils are entombed at some horizons. Following the deposition of the Shensi series, the North Shensi basin gradually increased in depth. In this deeper water was deposited the thin-bedded, argillaceous limestone of the Upper Jurassic Anting formation, which contains fish fossils belonging to the genus *Pholidophorus*. This genus has been found in the Triassic and Jurassic beds of Europe, South Africa, and North America, which are mostly of fresh-water origin. Thus it is seen that the Shensi series is mainly a continental deposit, in part of fluvial or lacustrine origin. The Upper Jurassic sediments are mainly fresh-water, lacustrine deposits.

CONCLUSION

The seeming impossibility that the Shensi oil could have migrated from marine formations indicates that this oil originated within the Shensi series, which is of continental (fluvial and lacustrine) origin. In view of the small size of the oil seepages, the presence of many dry holes and inferences of non-marine origin of the oil, this field probably has little commercial value. But oil does exist in this field, and small amounts have been produced. If good structures favorable for the accumulation of oil can be found, it seems probable that a small production of oil could be obtained. Unfortunately, favorable structures are very rare.

SZECHUAN

STRATIGRAPHY[8]

Feihsienkuan shale.—This formation consists essentially of purple shales with thin layers of limestone. Pelecypods, especially the genus *Pseudomonotis*, are very abundant at many horizons. It is about 200 meters thick. Its age is Lower Triassic.

Chialingchiang limestone.—The Feihsienkuan shale is conformably overlain by the Chialingchiang limestone, which consists mainly of dolomitic limestone and gray limestone, containing foraminifera and pelecypods. Outcrops of the Chialingchiang limestone are mainly found along the axes of anticlines. The formation is about 600 meters thick. Its age is Middle to early Upper Triassic.

Hsiangchi coal series.—The Chialingchiang limestone is disconformably or unconformably overlain by the Hsiangchi coal series, which consists mainly of grayish white coarse-grained sandstones

[8] C. H. Pan, "Oil Prospecting in Szechuan Province," *Oil Weekly* (February 22, 1937).

with gray and black shales, and contains several thin coal seams. It attains a thickness of about 500 meters. It is Lower Jurassic in age.

Cretaceous.—The Cretaceous is essentially composed of purple-red shales, clays, and gray and red sandstones. About 270 meters above the base of the red beds are thin limestones intercalated with black shales, containing very abundant pelecypods, which commonly belong to the genera *Cyrena* and *Unio*. The lower part is generally called the Tzuliuching formation, and the upper part the Chiating formation. The latter is distinguished from the former by the deep red color, which contrasts with the gray of the former. The red beds are widely distributed throughout the Szechuan basin, and are no less than 2,000 meters thick.

STRUCTURE

Szechuan has a typical basin structure. Around the border of the province, the older Paleozoic rocks crop out, forming high mountain ranges. Within the basin, Cretaceous red beds are widely distributed. This basin has suffered more intense compression than the North Shensi basin. Therefore many pronounced parallel anticlines and synclines have been formed, with a regional northeast-southwest trend. The Jurassic and Chialingchiang limestones generally crop out along the strong anticlinal axes.

OIL SEEPAGES AND OIL SANDS

Oil seepages are rare in Szechuan province. As a matter of fact, only two have been discovered, one in Shihyoukou, Pahsien, and the other in Shuichiatsao, Tahsien. Both of the oil seepages are near anticlinal axes. The surface rocks of the two districts all are Cretaceous red beds belonging to the Tzuliuching formation.

Oil sands, but no oil seepages, occur in Penglaichen, which belongs to Pengchihsien. The oil was discovered by the natives in drilling for gas. In 1900–1901, about 30 wells were drilled but only two of them produced a small amount of oil. These were soon exhausted. The total oil production has been less than 67 barrels. The surface rocks are Cretaceous red beds belonging to the Tzuliuching formation or the lower part of the Chiating formation. The structure is a very gentle brachy-anticline, trending north and south. Since the wells are only 70 meters deep, the oil sand is Cretaceous in age.

According to H. C. Tan and C. Y. Lee,[9] in the Fushun-Loshan area there are about six oil sands which were discovered by the

[9] H. C. Tan and C. Y. Lee, "Oil Fields in Szechuan Province," *Geol. Survey China Bull.* 22 (1933).

natives drilling for salt. Two of these are in the Chialingchiang limestone, two in the lower part of the Hsiangchi coal series and two in the Lower Cretaceous.

SOURCE BEDS

The oil found in Jurassic and Triassic rocks of the Fushun-Loshan area may have migrated from the Chialingchiang limestone, which is of marine origin. It does not fall within the scope of this paper to discuss this area. Here the writer only wishes to discuss the oil of Shihyoukou, Tahsien, and Penglaichen. It is now generally believed that although oil is a migratory fluid, the vertical migration (across the bedding) is generally difficult, and the lateral migration (parallel with the bedding) is easy for a somewhat longer distance.[10] Only where a fault is present, can oil pass through the avenue of the fault and migrate for a long distance. Therefore, where there is no fault, it is reasonable to search for the source bed near the oil reservoir. Both in Shihyoukou and Tahsien the surface rocks belong to the Tzuliuching formation, and there is no evidence of faulting. It seems that the oil of the seeps of Shihyoukou and Tahsien could not have migrated a very long distance. But which bed is the most likely source bed? In the Tzuliuching formation, the rocks are generally red shales and gray sandstones, scarcely containing any organic materials. Therefore, these barren beds are not likely to be the source of the oil. Seemingly the only possible source bed is the Tzuliuching limestone. About 33 miles south of Shihyoukou, between Kaishitung and Chuantangchiao, the Tzuliuching limestone consists of three thin layers of limestone intercalated with black shales, which are crowded with pelecypod fossils. The pelecypods generally belong to *Unio* and *Cyrena*, which are regarded as of fresh-water origin. West of Shihyoukou near Ipinchang, the corresponding bed consists mainly of black and yellow shales with a layer of impure limestone. Here this bed is about 26 meters thick. The two genera *Unio* and *Cyrena* are also very abundant. On the way from Wanhsien to Tahsien the black shales (corresponding with the Tzuliuching limestone horizon) full of similar pelecypods were also found. The writer believes that the Tzuliuching limestone, about 560 meters below the surface in Shihyoukou, is the source bed of the oil seepages of Shihyoukou, Tahsien, and the oil sand of Penglaichen. According to the record of Shihyoukou, at the depths of 46.7, 89.7, and 114.6 meters, oil traces were struck, but below the Tzuliuching limestone horizon no oil

[10] F. H. Lahee, "A Study of the Evidences for Lateral and Vertical Migration of Oil," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), p. 329.

showing was found. This fact indicates that the Tzuliuching limestone is probably the source bed of the oil seep, and that the oil probably did not come from the Jurassic and marine Triassic. If the oil of Shihyoukou migrated from the Jurassic or marine Triassic, then the basal Tzuliuching formation and the Jurassic bed would have a chance to have a showing of oil in certain beds. The well record of Shihyoukou below the Tzuliuching limestone bed does not show any oil trace. Moreover, if the oil came from the older marine bed, it would have been dissipated in the Jurassic before reaching the surface, because the Jurassic consists mostly of very thick coarse-grained sandstone. If oil should pass through these thick, coarse-grained sandstones, all of it would easily be absorbed. In this paper the writer's purpose is to prove the possible source bed of the oil seeps of Shihyoukou and Tahsien and the oil sand of Penglaichen. However, it would not be correct to say that the marine Chialingchiang limestone, Feihsienkuan shale, and other formations would have no possibilities of generating oil, inasmuch as the oil traces from the salt wells of Tzuliuching are probably from the main Triassic bed.

CONCLUSION

From the foregoing discussion, it seems highly probable that the oil of the seeps of Shihyoukou and Tahsien, and the oil of Penglaichen, comes from the Tzuliuching limestone, which is lacustrine in origin, as indicated by *Unio* and *Cyrena* which are fresh-water pelecypods. Moreover, this Cretaceous oil probably has no commercial value.

DISCUSSION

Since almost all the oil fields of the world are marine in origin, it is no wonder that most geologists believe that oil can not originate in fresh-water sediments. But the Powder Wash field of northwestern Colorado, the writer believes is non-marine in origin, and has a large production. The oil of North Shensi is evidently non-marine in origin, and the Cretaceous oil of Szechuan also probably comes from fresh-water sediments,—the Tzuliuching limestone. From the evidence as stated, it is clear that in exceptional cases oil can also originate from the fresh-water sediments, and may be of commercial value.

F. W. Clarke said:[11]

> Wherever sediments are laid down, inclosing either animal or vegetable matter, there bitumens may be produced. The presence of water, preferably salt, the exclusion of air, and the existence of an impervious protecting stratum of clay seem to be essential conditions toward rendering the transformation possible.

[11] F. W. Clarke, "Data of Geochemistry," *U. S. Geol. Survey Bull. 770* (1924).

Evidently the conditions when the source beds of North Shensi and the Cretaceous of Szechuan were deposited fulfilled what Clarke described.

According to J. Claude Jones,[12] when some wells were drilled in Lake Lahontan, northwestern Nevada, oil globules came from several sands which are recent lake deposits. This is evidence that oil can originate in lake deposits.

We now know that anaerobic bacteria play an important part in the transformation of organic materials into petroleum. Under anaerobic conditions, the organic materials are decomposed by bacteria into lower fatty acids, methane, carbon dioxide, and water.[13] Anaerobic bacteria are probably much more abundant in salt water than in fresh water. That is why petroleum is generally generated in marine deposits, and oil shale generally formed in fresh-water sediments.

Jones clearly pointed out this relation as follows.

> In fresh water only coals and oil shales will form, for the bacterial decay does not remove a sufficient amount of the tissues of the plants or appreciably act on the fats to produce petroleum. When the salinity of the water rises above 3,000 parts per million the character of the bacterial decay is such as to eliminate largely the greater part of the organic matter and change the fats to petroleum.

The writer believes that, although lake waters generally contain less salt than marine waters, the anaerobic bacteria are generally insufficient to transform the organic materials into petroleum. But if the lake water evaporated through a long period of time, the salts would be highly concentrated, and eventually the salinity of 3,000 parts per million would be reached. In this condition the anaerobic bacteria would be able to transform organic materials into petroleum. In this connection, is seen the reason why the connate water from the oil reservoir is generally saline. Both North Shensi and Szechuan produce salt, and the connate water from the oil sands of North Shensi is also generally saline. This is an indication that the conditions when the Shensi series was deposited were suitable for the multiplication of bacteria, and so were favorable for the generation of oil.

Trask[14] has recently made extensive studies of the organic materials in recent marine sediments. He reports that in near-shore

[12] J. Claude Jones, "Suggestive Evidence on the Origin of Petroleum and Oil Shale," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 1 (1923), p. 67.

[13] H. E. Hammar, "Relation of Micro-Organisms to Generation of Petroleum," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), p. 45.

[14] P. D. Trask, "Petroleum Source Beds," *The Science of Petroleum*, Vol. 1 (1938), p. 43.

marine sediments the organic material ranges mainly from 1 to 7 per cent, but that the percentage in some lakes may be as high as 40, that in the Black Sea being 35. This indicates that the organic matter of lakes may exceed that of marine waters by a considerable amount. This condition is of secondary importance in the origin of oil.

WILLIAM J. MILLARD, the Engineers' Club, 32 West 40th Street, New York City (discussion received, September 15, 1941).—To make this article clearer, the following column was taken from an article by C. H. Pan in *Bulletin 24* of the China Geological Survey.

NORTHERN SHENSI

Age		*Thickness (Meters)*
Pliocene and Pleistocene	Loess and red clay	50–2,000
Cretaceous	Paoan series	2,000
Upper Jurassic	Anting formation	80
Lower Jurassic	Wayaopu Coal series	800
Upper Triassic (Keuper-Rhaetic)	Yenchang formation	1,000
Permo-Triassic	Shihchienfên series	600–800
Thick section of folded Paleozoics below and surrounding the basin		

COLUMN IN TAHSIEN OIL FIELD IN SZECHUAN

Lower Cretaceous	Tzuliuching formation (Oil sand 700 meters above bottom)	800
Jurassic	Hsiangchi Coal series	500
Triassic	Chialingchiang formation	500
Lower Triassic	Feihsienkuan shale	200

It seems that the author of this paper has presented facts that point to these continental deposits as being the source of the petroleum found thus far in China. There are several bodies of shale near to the oil horizons, which might be sources. Some of the observed seeps are from shale strata.

Of interest is the question as to whether oil will ever be produced in commercial quantities in China. A review of drilling shows that since 1907 several attempts have been made to secure production by drilling. The highest production was 60 barrels per day of 37° Be'. oil in a well at Yenchang, Shensi. Several wells were drilled in the general area, the deepest of which was 3,545 feet. Showings from the well drilled are given as at 280, 1003, 1378, 1420, and 1776 feet. Another well had showings at 170, 255, and 365 feet. This indicates possibilities of production in commercial quantities, as sufficient cover seems available. What production was obtained fell off rapidly. This may have been due to the manner in which the wells were cased and handled. There may have been a lack of skilled technicians.

Competent and experienced personnel is necessary to any operation involving oil search. About a year ago, some drilling machinery passed through Yunnanfu from the port of Haiphong in Indo-China. It was bought to piece out some equipment in Szechuan. However, from well informed sources, it was learned that the material was too heavy to be used with the drill on hand in the field. Threads were badly mashed and the parts in bad condition.

A consideration of all the geological and drilling data leads one to believe

that there is a real possibility of developing some commercial production. This production would be small compared with production in America; but it might be comparable with some of our regions where wells are small in initial production. It would certainly be a great boon to the new industries that are being built up in Szechuan.

IMPROVED METHOD OF HANDLING MICROFILM COPY[1]

H. T. U. SMITH[2]
Lawrence, Kansas

In a recent issue of the *Bulletin,* Campbell[3] has pointed out the value of microfilm copy in geologic research. Through this medium, the many volumes and maps of the United States Geological Survey Library,[4] and of other leading libraries, are brought within reach of any geologist, wherever he may be located. For some workers, however, the inconvenience entailed by usual methods of handling microfilm may have presented a decided obstacle to its ready use. For reading, special equipment using transmitted light is necessary. Filing methods are rather primitive, the film generally being either stored in rolls or placed in envelopes in strip form, neither method permitting very rapid access to page references. To avoid these difficulties, the writer has evolved a simpler and more direct method of handling the copy, using only standard equipment for reading and filing. This method consists essentially in using contact prints made from the microfilm negative, rather than the latter by itself. The prints are mounted on cards, filed in a standard card file, and read with the aid of a hand lens or low-power binocular microscope. For this method, it is essential that the negatives be of uniform density of tone, of finest possible grain, and of maximum sharpness of definition. Copy meeting these requirements may be obtained from agencies specializing in this type of work, or may be prepared by using a precision miniature camera, such as the Leica or Contax. Negatives showing either one or two pages per frame (24×36 mm.) may be used. The former are easier to read, and are more satisfactory for illustrations, but the latter are less expensive and more quickly mounted. Choice

[1] Manuscript received, October 8, 1941.

[2] University of Kansas.

[3] R. W. Campbell, "New Library Research Tool," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23 (1939), pp. 1567–69.

[4] "Bibliofilm Service in the Geological Survey," *Science*, Vol. 88 (1938), pp. 517–18.

between the two sizes depends on the size of the page to be copied, on the size of type, on the illustrative material, and on considerations of economy versus ease of reading.

Contact prints may be made either in single strips of any convenient length, or, if the film is first cut into sections of 6 frames each, 5

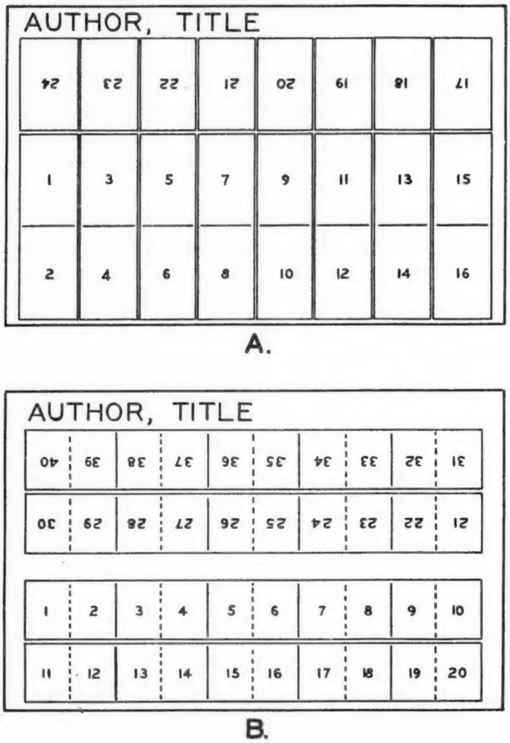

FIG. 1.—Diagrams showing arrangement of contact print strips on 5×8-inch cards. *A* shows copy of one page per frame, and *B* shows copy of two pages per frame. The numbers indicate sequence of pages in the material copied.

of these may be placed side by side and printed simultaneously on a single sheet of 8×10-inch paper. Tight contact between film and paper is absolutely essential, and a point source of light is desirable. Gloss finish is best. If carefully made, the contact prints will show all the detail of the negative with perfect sharpness.

After processing, the sheet of prints is backed with Kodak dry-mounting tissue, cut, trimmed, and mounted on stiff 5×8-inch cards,

using an adjustable electric flatiron. If a single-page frame is used, the strips are mounted vertically on the card, as indicated in Figure 1-A. If a double-page frame is used, however, the strips are mounted across the card, as shown in Figure 1-B. In either case, it is necessary, if a standard model of binocular microscope is used for reading, that the prints along one edge of the card be mounted upside down, so that the frame of the microscope will not interfere with the reading position.

For reading the mounted copy, a magnification of 5 to 10 diameters is necessary. For short reading periods, a well corrected hand lens is entirely satisfactory. For longer reading periods, however, a low-power, wide-field binocular microscope is more convenient and less fatiguing.

Although the method outlined above involves a slight added cost and entails some additional time for making the mounts, these considerations are far outweighed by the advantages gained: (1) compactness of the copy—48 pages may be mounted on the two sides of one card, using single-page frames, or 80 pages with double-page frames; (2) ease of filing and subsequent reference, especially to specific pages in long articles or books; (3) adaptability to copy of from a few pages to hundreds of pages in length; (4) easier reading of black-on-white than of white-on-black material; (5) elimination of the need for transmitted light and special reading equipment; (6) elimination of the need for special care in handling the copy to avoid marring; (7) ease of carrying and using the copy under field conditions; and (8) ease of making additional copies from the same negative.

CORRECTION

HIGH-PRESSURE YATES SAND GAS PROBLEM, EAST WASSON FIELD, YOAKUM COUNTY, WEST TEXAS

In the article, "High-Pressure Yates Sand Gas Problem, East Wasson Field, Yoakum County, West Texas," by Alden S. Donnelly, in the October *Bulletin*, Vol. 25, No. 10, page 1895, the second line in the bleed-off calculations near the bottom of the page should read:

$$-0.3192 \text{ cu. feet/foot } 7\tfrac{5}{8}\text{-inch external volume}$$

$7\frac{5}{8}$ being substituted for $8\frac{5}{8}$.

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DISCUSSION

GRAYWACKES AND THE PETROLOGY OF BRADFORD OIL FIELD, PENNSYLVANIA[1]

PAUL D. KRYNINE[2]
State College, Pennsylvania

In the July issue of the *Bulletin*, Dr. Parke A. Dickey published a detailed review and a discussion of my paper on the "Petrology and Genesis of the Third Bradford Sand."[3] Although many of his statements warrant some correction, I shall, for the sake of brevity, discuss only four or five of them which are of such general nature as to be of interest to most petroleum geologists.

Dr. Dickey makes the statement that I have given " . . . insufficient credit to the more comprehensive work of C. R. Fettke."[4] On page 10 of my paper I state that: "The geology, subsurface stratigraphy, and production data of the Bradford field have been described in *considerable detail* by Fettke and the reader is referred to this work for general information." It appears then that I have given proper credit to Dr. Fettke in this general field. In the more restricted province of petrology—which is the subject of my paper—Dr. Fettke devotes only two pages of his 1938 report to the "mineralogy" (and petrography) of the Bradford sand. Hence, obviously, our two publications cover entirely different fields and do not overlap.

Dr. Dickey apparently misunderstands my position in respect to the origin of the Bradford sand. He says, "Dr. Krynine concludes that the Bradford sand was deposited in a delta which he compares with the Mississippi delta. This idea is not new, and was advanced by Dr. Fettke in 1934. . . ."[5] *This is precisely what I do not conclude.* I compare the Bradford delta not with the Mississippi, but with an entirely different type of coalescing small deltas which form trends along shore lines. On pages 82 and 83 of my paper I say (italics added for this discussion):

> Finally, the large scale lensing and channeling of the Third sand appears to correspond in many respects to the published descriptions of large deltas such as the Mississippi. *It would be entirely erroneous, however, to suppose that the delta was formed by one very large river.* It may rather have been a series of coalescing deltas formed by a series of fairly small or at best medium sized streams. Such deltas individually small,

[1] Published by permission of the director of research, School of Mineral Industries, The Pennsylvania State College, State College, Pennsylvania.
Manuscript received, September, 1941.

[2] School of Mineral Industries, Pennsylvania State College. Member, Committee on Sedimentation, National Research Council.

[3] P. D. Krynine, "Petrology and Genesis of the Third Bradford Sand," *Pennsylvania State College Mineral Industries Experiment Station Bull. 29* (1940). 134 pp.

[4] C. R. Fettke, "The Bradford Oil Field," *Pennsylvania Topog. and Geol. Survey Bull. M 21* (Harrisburg, 1938). 454 pp.

[5] C. R. Fettke, "Physical Characteristics of Bradford Sand and Relation to Production of Oil," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 2 (February, 1934), pp. 191–211.

but very extensive when added together, are a feature of subsiding coastal plains in regions of heavy rainfall such as are found at the present time in parts of Central America.

This is obviously an entirely different interpretation from Fettke's two-lobed delta.

An entirely erroneous impression is given of my hypothesis of Appalachian orogeny and sedimentation when Dr. Dickey uses the term "Upper Paleozoic" when referring to the Upper Ordovician, Silurian, and Devonian sediments,—which are the formations said in my paper to be made of reworked earlier sediments.[6] As a matter of fact, I believe that the Pennsylvanian and Permian of the Appalachian trough are quite different in provenance from the Middle Paleozoic discussed in my paper.

Two of Dr. Dickey's statements concerning the evaluation of petrographic evidence and petrographic nomenclature are of sufficient general interest to all petroleum geologists to warrant a more detailed discussion.

The value of petrographic evidence may be debatable ("vague" and "not sufficiently substantiated" according to Dickey). It may be pointed out that much geologic evidence (and not petrographic evidence alone) is entirely inferential. A correct evaluation of specialized technical circumstantial evidence is admittedly difficult but is far from impossible. It is important, however, to make use of all techniques and methods available to scientists in order to facilitate the solution of a problem.

Frequently, petrographic evidence, especially based on the study of *thin sections*, can provide a welcome short-cut to the genesis, hence, to the general character and probable distribution of a given "sand" body. It is true that the exhaustive study of an oil pool requires the compilation of hundreds of well logs, but the genetic characteristics of an oil sand can be inferred very quickly from a competent petrographic examination of only a very few critical thin sections.

Nowhere is this truer than in the comparison of the graywackes of the Third Bradford "sand" and of the quartzose sandstones of the Venango fields. Although to prove conclusively the sand-bar character of the Venango pools required years of conscientious field work,[7] nevertheless, the radical distinction between the Bradford and Venango sedimentary types can be

[6] Dr. Dickey says, "Most geologists will grant that the upper Paleozoic sandstones (all of which Krynine prefers to call quartzites or graywackes) were largely derived from pre-existing sediments. Some perhaps will not admit that all can be traced ultimately to the Cambrian quartzites."

This statement calls for the following comments. (a) None of the formations discussed in my paper is of Upper Paleozoic age. (b) The bulk of the constituents of the Bradford and other Devonian *graywackes* is traced by me *directly* to the Ordovician slates and phyllites and ultimately to the pre-Cambrian (and only a small fraction of the material goes to the Cambrian). This is explained at length on pp. 83, 85, and 86 of my paper and is shown graphically in Figure 3. (c) Conversely the Tuscarora and Oriskany *quartzites* are traced by me both directly and ultimately to the Cambrian sedimentary quartzite. (d) I have failed to see in the literature any mention whatsoever of point (b) outside of Mencher's 1939 paper on the Catskill (*Bull. Geol. Soc. America*, Vol. 50, pp. 1761–94); and no proof was ever presented concerning point (c) although some petrographers like Martens have recognized the reworked character of some of these quartzites.

[7] P. A. Dickey, "Oil Geology of the Titusville Quadrangle, Pennsylvania," *Pennsylvania Topog. and Geol. Survey Bull. M 22* (1941). 87 pages.

established in the laboratory on critically selected specimens in less than a day's time.

This is not to imply that the study of sediments in thin sections is easy. On the contrary, it is very difficult. As Professor Knopf of Yale University says:[8] "The microscopic interpretation of sedimentary rocks is much harder than that of igneous rocks." The rewards of such studies, however, are great.

Such petrologic studies obviously require the use of a rather precise terminology, especially in the nomenclature of medium-grained clastic rocks.

The Bradford "sand" is described as a "graywacke" in my paper. Dr. Dickey questions my usage of the term graywacke. According to him, "definitions of the term differ markedly" and "the Bradford sand does not fit exactly any of these very diverse definitions." Dickey quotes Holmes,[9] Twenhofel,[10] and Milner (1929 edition).[11] Unfortunately, Dickey fails to give complete, unexpurgated quotations from Milner and Holmes. If this error is rectified and the complete unabridged definition is given, then it will be seen that the Bradford graywacke is indeed a graywacke.[12] Twenhofel's first definition of the term graywacke is rather unique and is not in accordance with other authorities, but his second definition fits the Bradford "sand" very nicely.

To clarify this matter, I refer the reader to the textbooks of Kemp,[13] Grout,[14] Milner (1940 edition),[15] and Pirsson and Knopf,[16] who give correct definitions of graywackes based on the proper and classical usage of the term. These definitions are substantially in agreement and Knopf's (p. 340) definition is here quoted as an example.

> *Graywackes.* These are sandstone-like rocks of a prevailing gray color sometimes brown to blackish which in addition to quartz and feldspar of an arkose contain rounded

[8] Personal communication.

[9] Arthur Holmes, *The Nomenclature of Petrology*, 2d ed. (London, 1928), p. 113.

[10] W. H. Twenhofel, *Principles of Sedimentation* (1939), pp. 289–90.

[11] Henry B. Milner, *Sedimentary Petrography*, 2d ed. (1929), p. 281.

[12] For instance, Dickey quotes Milner (p. 281) thus: "a sandstone compounded of quartz and miscellaneous rock particles of diverse origin, the latter often in excess of the detrital quartz." *To this should be added* (pp. 281–282) "the very mixed character of these rocks is usually discernible at a glance, while the grey, green and *darker* color is common, often highly micaceous, well bedded, usually void of recognizable organic remains" and "Min. comp.—Rock particles include fragments of basic rocks, *slates, sandstones*, and volcanic lavas. Quartz, *chert, quartzite, mica, iron ores*, and usually scanty accessory minerals." *Now this is an almost perfect description of the Bradford graywacke.*—Italics throughout are mine.—P.D.K.

Similarly, Dickey fails to give the full quotation of Holmes which describes the graywackes (p. 113, 1st edition) as "usually dark in color, strongly cemented, often with an argillaceous binding, and occur characteristically among the older formations."

[13] J. F. Kemp, *A Handbook of Rocks*, 6th ed. (1940). Definition of graywacke on p. 165.

[14] F. F. Grout, *Petrography and Petrology* (1932). Definition of graywacke on p. 275.

[15] Henry B. Milner, *Sedimentary Petrography*, 3rd ed. (1940). Definition of graywacke on p. 372.

[16] L. V. Pirsson and A. Knopf, *Rocks and Rock Minerals*, 2d ed. (1925). Definition of graywacke on p. 340.

or angular bits of other rocks such as fragments of shale, slate, quartzite, granite, felsite, basalt, etc., or of varied minerals, hornblende, garnet, tourmaline, etc.

This definition fits the Bradford "sand" exactly, and no wonder, for it is the classical definition of a graywacke based on the original usage of the term. For such an original, correct usage I refer the reader to Naumann's[17] textbook published in 1850. This stupendous three-volume opus gives the following definition of graywacke, a definition strikingly similar to that of Pirsson and Knopf (Naumann, Vol. I, pp. 697 and 698).

Körnige Grauwacke. Eckige oder abgerundete Körner von Quartz und kleine Bröcken von Kieselschiefer, Thonschiefer und anderen Gesteinen, zu welchen sich bisweilen auch Feldspath Körner gesellen, sind durch ein Bindemittel verkittet, welches wesentlich aus Thon und Kieselerde besteht. Die Imprägnation des Cämentes mit Kieselerde verleiht dem Gesteine oft eine grosse Festigkeit und bedeutende Härte. Seine Farben sind meist grau, besonders gelblichgrau, grünlich grau, blaulichgrau und rauchgrau.

This is followed by a description of fine-grained graywacke ("Schiefrige Grauwacke") rich in mica (like the Bradford graywacke) and of "Grauwackenschiefer" which is the equivalent of the Bradford siltstones and microconglomerates. Please note that the emphasis is on slate and shale fragments besides quartz and on the color.

All of this discussion about graywackes has a very practical bearing on petroleum geology. Petrographic nomenclature is admittedly a somewhat arid subject.

However, it is necessary to understand that different types of medium-grained clastic sediments (normal sandstones, quartzites, arkoses, and graywackes) probably occupy, in the successive stages of the geomorphic and tectonic development of a continental land mass, a position similar to that of acid, intermediate, and basic igneous rocks in the scheme of magmatic differentiation.[18]

Graywackes, to be specific, are a typical sediment of certain substages and facies of the geosynclinal stage. This fact has been recognized to some extent in Great Britain and I refer to Jones'[19] excellent paper on the subject.

In the coming search for stratigraphic traps, a vastly improved knowledge of sedimentation and sedimentary petrography will be advantageous to all members of the profession. The first step in this direction is the ability to differentiate the types of medium-grained clastic sediments and to interpret their significance.[20]

[17] Carl Friedrich Naumann, *Lehrbuch der Geognosie* (Leipzig, 1850). 3 volumes.

[18] This concept is to be discussed in a paper which I am preparing for presentation at the December meeting of the Geological Society of America.—P.D.K.

[19] O. T. Jones, "On the Evolution of a Geosyncline," *Quar. Jour. Geol. Soc. London*, Vol. 94 (1938), presidential address, pp. LX-CX, Pls. A-D.

[20] Obviously such paleogeographic studies will not be facilitated if sandstones, graywackes, and quartzites are left undifferentiated, as is done by Dr. Dickey when he says, ". . . the upper [*sic*] Paleozoic sandstones (all of which Krynine prefers to call quartzites or graywackes) . . ."

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and available, for loan, to members and associates.

GEOLOGY, 1888–1938. FIFTIETH ANNIVERSARY VOLUME OF THE GEOLOGICAL SOCIETY OF AMERICA

REVIEW BY CHARLES W. TOMLINSON[1]
Ardmore, Oklahoma

Geology, 1888–1938. Fiftieth Anniversary Volume of the Geological Society of America (New York, June, 1941). 578 pp., 15 figs.

The Fiftieth Anniversary Volume of the Geological Society of America is a comprehensive review of the development of our science in the last 50 years, by 21 authors, each eminent in the special field of which he writes. The chapters vary in length from 8 to 44 pages,—depending, apparently, more upon the relish of the author for this type of historical and compendious writing than upon the abundance or merit of his material.

No such history can be written without including a sketch of the present status of knowledge and theory in the subject reviewed. Such a summary is offered by each of the authors,—in some cases almost to the exclusion of historical material, although other chapters include careful reviews of the appearance of new facts and ideas, decade by decade, beginning with well drawn pictures of the science of 1888. Most of the chapters are accompanied by extensive bibliographies of literature consulted.

The volume can be recommended enthusiastically to every geologist, commercial or academic, as an excellent means for bringing himself up to date, in a general way, with those branches of geology outside his special field, with the progress made in them since his college days. This procedure can even be urged upon the authors of the volume, for all chapters except their own. Certainly no one man could have written all of them, nor more than one or two of them, with equal authority or clarity, although few of us are confined in interest or practice to one of these 21 fields.

Six of the authors are members of the American Association of Petroleum Geologists,—three of them past-presidents. It is sad to note that for both Reed and Barton, this was a final contribution to geologic literature. Reed's able review of Structural Geology is spiced by the good-humored and effective satire so familiar to us in his public addresses as well as in his writings. Barton's chapter on Exploratory Geophysics is typically thorough and complete. Heroy's summary of Petroleum Geology, past and present, is so accurate and clear a survey that it might well be quoted in future textbooks.

Several of the writers let us share their philosophic musings on the merits and demerits of geologic reasoning, methods, and current rate of progress relative to other sciences. Graton deprecates our tendency to wide and vigorous dissent, and on the other hand our sheep-like following of plausible new ideas before they have been established by proof. He urges us to "tighten up our reasoning." Both he and Bryan caution us against the natural tendency to generalize from limited data,—to overstress evidence which is in the fore-

[1] Manuscript received, September 30, 1941.

ground of our personal experience. Graton and Knopf note the enormous growth of geologic literature, beyond the capacity of any one man to digest; yet Graton joins Barton and Mead in urging more complete publication of data obtained at private expense. The problem of whether to restrict or to multiply new names is cited by Raymond in Paleontology and also by Knopf in Petrology.

The interweaving of one branch of geology with another is evidenced by mention of submarine canyons in the chapter on Structural Geology as well as in that on Oceanography. The most positive statement on continental drift appears in the section on Sedimentation. Snatches of historical geology, of paleogeography, and of orogeny appear in several chapters, but none of these subjects is treated as a separate unit. Our science is difficult to subdivide.

The following quotations give a run-of-mine sample of the book, weighted a little heavily on the practical side. They are among the passages that happened to arrest the attention of one petroleum geologist. The fact that they grow more numerous as the page numbers grow larger reflects the arrangement of subjects in the volume,—more or less in order of their standing as "pure science."

STRIKING EXCERPTS FROM THE FIFTIETH ANNIVERSARY VOLUME OF THE GEOLOGICAL SOCIETY OF AMERICA: *Geology 1888–1938*

KIRK BRYAN, Physiography. P. 7: Even the Appalachians, the area made classic by Davis, are at the moment the subject on a many-sided controversy as to the significance of many individual land forms and as to the sequence of geomorphic events. P. 13 [quoted from Gregory]: "The influence of locality is plainly seen . . . "[in the opinions of different physiographers].

RICHARD FOSTER FLINT, Glacial Geology. P. 27: The opinion is now general that the bulk of the loess is eolian but that a minor though conspicuous proportion is aqueous . . . The loess of the Mississippi basin is derived partly from the drift and partly from nonglacial fine-grained sediments in the dry country to windward, but there . . . still are various shades of opinion as to the relative contribution from each source.

P. 29: Recent studies of the thickness of drift and the subdrift rock surface in Ohio are a well-log by-product of petroleum work.

P. 36: . . . The view toward which opinion is at present converging—namely, that glaciers move by plastic flow, the flowing interior mass grading upward and outward into a zone of brittle, fractured ice which rides upon it. P. 37: . . . The repeated occurrence of late Pleistocene dead ice may be visualized as the result of thinning by wastage until the base of the outer, brittle zone reached down to the subglacial floor.

HENRY C. STETSON, Oceanography. P. 64: Whatever their origin these submerged canyons offer the only available opportunities for getting at the older formations beneath the mantle of Recent veneer, for in places their walls stand as cliffs. . . . The fossiliferous fragments broken from the outcropping ledges indicate that these valleys are comparatively young. This adds to the complexity of the problem because we cannot retreat into the security of the distant past when called upon for an explanation of their origin. P. 65: On the east coast [of the U. S.] the formations are all sedimentary, ranging from Upper Cretaceous through the late Pliocene. . . . The walls of the west coast canyons likewise consist, for the most part, of sedimentary formations, the youngest of which are Pliocene. . . .

PERCY E. RAYMOND, Invertebrate Paleontology. P. 98: Invertebrate paleontologists are constantly accumulating masses of information toward a study of evolution, but few of them have concerned themselves with the theories. . . . The school of experimental

biologists has so firmly convinced them that they can never prove anything, that, whatever their beliefs, paleontologists have generally chosen to remain silent. Probably most are Lamarckians of some shade . . . Recently orthogenesis has become popular. . . This idea is natural for the paleontologist, whose lines of descent are necessarily straight. But there are straight lines in all directions in most groups; one is just as orthogenetic as another. Some lead to survival, some to racial suicide. But it is a question whether the influences which produce the result are wholly inherent. No living thing has ever controlled its environment. [Reviewer's note: Mother Nature's experiments in evaluation have occupied a million times as many years as those of the "experimental biologists."]

P. 99: . . . It is only the rare species which are not highly variable. . . . Descent has been a gradual process. . . . It is not easy to get general agreement as to the proper limitation of . . . species. There probably will always be "lumpers" and "splitters," although the latter have rapidly gained the ascendancy in recent years. At the present time, any characteristic, however slight, which enables an expert to distinguish between specimens from zones of different ages, is looked upon as of specific importance, whereas each species, within its own zone, may show much greater variability. This is a course dictated by utilitarian purposes, and by some it is carried to such an extreme that the locality seems to be the chief guide to identification.

ALFRED S. ROMER, Vertebrate Paleontology. P. 133: . . . While the theory . . . that modern man arose in Europe from [Neanderthal man] . . . seems to be unfounded, recent neanderthaloid specimens from Palestine . . . show suggestive intermediate characters. P. 134: Certain English finds, however, are a stumbling block . . . These older forms are further advanced cranially than the much later neanderthalers . . . We are still far from a satisfactory solution of the problems of human evolution.

CHESTER STOCK, Prehistoric Archeology. P. 144: The view that it [the paleontological record of Man in the Old World] extends over the whole of the Pleistocene and into the late Pliocene has shifted to one in which all known stages are now referred to the Pleistocene, and furthermore, that only a fraction of the epoch is represented by this history. P. 154: . . . . There does not appear to have been demonstrated an occurrence [of man] in the New World comparable in antiquity to those of the late Pleistocene of the Old World.

EDWARD W. BERRY, Paleobotany: P. 171: . . . Enormous additions have been made to the known fossil forms [of the Flowering Plants]. The oldest of these [Lower Cretaceous] are in no way primitive . . . ; thus one is inevitably led to conclude that the origin of the Flowering Plants must have been very remote.

RAYMOND C. MOORE, Stratigraphy. P. 203: The advent of new organisms has been deemed to signify the beginning of a new stratigraphic order. . . . This has resulted in the gradual lowering of intersystemic boundaries. . . . These changes seem partly proper and partly improper, but it seems clear that criteria other than "new appearances" must be considered, and some of these, such as observed evidence of widespread disconformity, may be much more important than certain paleontologic aspects.

P. 204: Some . . . formerly inferred provinces are now believed to reflect merely differences in ecology. . . . At the same time, no doubt exists concerning separation of so-called Atlantic and Pacific sea ways of Paleozoic time in eastern North America, and, accordingly, it is not possible to make any reliable correlation between individual formations of one province and those of the other. Cosmopolitan faunas spread widely over North America and other continents during some epochs of geologic history, providing excellent basis for interregional correlations.

P. 216: The Wegener hypothesis of wandering continents . . . is based very largely on stratigraphic evidence . . . The opposing doctrine of the permanence of continental areas and ocean basins is supported strongly by many geologists, including stratigraphers, but they seem increasingly to be placed in a defensive position. [Compare Reed's comment, p. 243, quoted below.]

PARKER D. TRASK, Sedimentation. P. 227: There are many areas in the ocean more than 100 miles square in which no bottom samples have yet been obtained. A big field

of research in oceanic deposits lies ahead in the study of subsurface layers procured by long cores.

P. 228: The causes of stratification, though seemingly obvious, are not yet understood thoroughly. Among other things, it is difficult to understand why unconsolidated recent marine deposits as a rule are so poorly stratified, whereas ancient consolidated sediments generally are well stratified.

P. 231: . . . The effect of sea water on the exchange of bases in clays. This work [of the U. S. Geological Survey] has suggested that much more sodium is absorbed by sediments on the sea bottom than has formerly been suspected. Detritus transported by rivers, upon reaching the sea, ordinarily gives up calcium and manganese and takes on sodium, potassium, and magnesium. Thus the composition of sea water depends upon the solid as well as upon the dissolved substances supplied by rivers. This exchange of bases in the sea . . . promises to be one of the most fruitful lines of research confronting students of sediments.

P. 232: . . . One of the main questions is whether the fine particles of calcium carbonate that form the bulk of most limestones represent material precipitated from solution or are the remains of shells of organisms. . . . The origin of dolomite is still a moot question.

P. 233: Sediments that are laid down upon ridges or on exposed places on the sea floor in recent years have been found in general to be more coarse-grained than those that accumulate in basins or protected places, regardless of depth of water. Evidently, currents are stronger at depth in the ocean than has hitherto been suspected.

Ralph D. Reed, Structural Geology. P. 243: To one, . . . the theory of continental drift may seem to be a great accomplishment that has freed the minds of men from the shackles of outworn superstition, . . . ; another might be equally sure that the recent inclination of a few geologists to flirt with this theory represents merely an unfortunate aberration.

P. 244: The errors of 50 years ago are likely to be recognized as ridiculous, while those of the present . . . may seem like revelation.

P. 245: The attempts of these pioneers to solve the problems of the submarine canyons suffered from a lack of detailed knowledge about the canyons and also about the Cenozoic history of the continent. Later students have had similar difficulties.

P. 249: As time goes on, the complexity of the orogenic history of a given range seems to increase. Some foldings seem to have taken place very suddenly; others throughout relatively long periods; and the better known examples of short-lived folding episodes seem to have taken place almost contemporaneously in parts of many geosynclines and also in many labile shelf areas throughout great parts of the world.

P. 250: A peculiar facies may be deposited in several narrow belts separated by belts of comparable width in which contemporaneous deposits of a very different facies were accumulating. . . . This fact, which is beyond controversy, suggests strongly the possibility that Alpine paleogeography may have been unduly simplified in the interest of an attractive but unproved assumption regarding facies. P. 251: That the present status of Alpine theory may not prove impregnable is suggested by the number of dissenters among the Alpine experts themselves. . . . Schaffer . . . makes the paleogeography of the Alps a little more complicated than it has been considered previously and thereby makes the structural evolution a great deal simpler.

P. 259: Most of the [structural] laws hitherto proposed have tended to rouse more skepticism than acclaim, but a few are already widely acknowledged to be probable, and interesting if true. . . . Explanations that are mechanically sound but historically erroneous. P. 261: . . . If we succeeded in validating the time law [synchronism of orogenic episodes] . . . we should be able to present the geophysicists with one of those massive facts for which they love to seek explanations.

M. E. Wilson, Pre-Cambrian. P. 298: . . . There are few features that suggest that the climate or other conditions of sedimentary deposition were any different even during the Early pre-Cambrian from that in later periods. P. 301: . . . Except for their more highly folded condition, there is no essential difference between the . . . sediments and lava flows of the Archean basal complex of the Canadian Shield and those of later age. . . . Attention will be directed more than formerly to the northern parts of the Shield and to a more intensive study of structure of the Archean.

EDWARD H. KRAUS, Mineralogy. P. 314: Crystallography has become an exact science and the basis for the interpretation of the phenomena characteristic of the solid state which are being studied so intensively by physicists and physical chemists.

ADOLPH KNOPF, Petrology. P. 336: . . . Opinions have continued to differ, ranging from Brögger's view that the fear of new names is a children's disease to that of Bowen, who regards most new names as unnecessary . . .

P. 339: The problem has shifted . . . from whether granites are the results of pure igneous fusion to whether they are igneous at all—whether they are in reality metasomatic, formed from pre-existing rock masses by the action of deep-seated emanations.

P. 340: Things discovered may become forgotten for decades and then be rediscovered.

P. 343: . . . The concept of a petrogenic epoch has largely supplanted the older concept of a petrographic province . . . P. 344: At present the idea is widely held that the parental magma of a given petrogenic cycle is basaltic, but we have no definite explanation of the source of this magma . . .

P. 345: All recent tendency has been to regard immiscibility definitely disproved as a factor in magmatic differentiation; yet the idea dies hard . . .

P. 346: The Sudbury nickel irruptive mass . . . has attained the distinction of having more written about it than any other of the world's igneous masses. The explanations proposed are correspondingly diverse. . . The ore instead of being a frozen melt is a replacement controlled by fractures.

P. 349: The great upswing in sedimentary petrology of recent years is largely a result of the enormous expansion of the oil industry.

P. 350: . . . The multiplication of journals in recent years cannot be regarded as an unmixed blessing.

HOWEL WILLIAMS, Volcanology. P. 374: The volcano [Kilauea] seems almost to breathe, rising and falling with the level of the magma in the conduits. P. 375 . . . There is a growing tendency away from the old view that igneous intrusion and volcanism are merely aftermaths of orogenesis and toward the view that magma itself is an active agent in crustal deformation.

Few volcanologists now deny that almost all volcanic depressions more than a mile in width are produced for the most part by collapse [rather than directly by explosive eruption].

P. 377: It seems, then, that under favorable conditions, . . . slight earth tides of luni-solar origin and even barometric changes may be adequate to affect the rate of gas escape and thereby the time of eruption. . . . Magnetic disturbances seem to be particularly marked just before an eruption.

P. 385: The characters of volcanic earthquakes, the nature of the accidental ejecta of volcanoes, and the abundance of collapse calderas testify to the shallowness of volcanic reservoirs. . . . These observations do not necessarily conflict with the view that ultimately all magma comes from a universal, subcrustal source.

P. 386: . . . Taliaferro has lately concluded that the principal source of silica [in cherts and siliceous shales] is from submarine hot springs and from the alteration of volcanic ash to hydrous silicate.

ESPER S. LARSEN, Geochemistry. P. 413: Our knowledge of colloids and of colloidal chemistry in ore deposition and other geological problems is still meager. We write much about mineralizers in magmas and in ore deposition but we know little about them.

H. E. MERWIN, General Geophysics. P. 421: . . . The old analogy that the earth is chemically like meteorites and that meteoritelike rock minerals have developed as the earth passed through an igneous stage of gravitative segregation. . . . This hypothesis has no active rival . . .

P. 427: If the changes [in the permanent magnetic field of the earth] are not cyclic they are geologically prodigious. The causes are not known. . . .

P. 428: . . . Moving with the sun, below the surface of the earth, are giant vortices of electric current which at the surface are whorls comparable in area with the North Pacific Ocean.

BENO GUTEMBERG, Seismology. P. 453: All known intermediate shocks, originating at depths between about 50 and 300 kilometers, are on Tertiary tectonic lines . . . and consequently show correlation with volcanism.

P. 461: The longest travel time observed for a wave through the earth (for a wave through the core, twice reflected at the surface of the earth) is about one hour. On the other hand, surface waves have been recorded for many hours while they repeatedly circled the earth.

P. 465: Another question is whether the prediction of earthquakes—if possible—would reduce the damage. . . . Thus far it has been impossible to predict the accurate location or the approximate time of a shock. Even if such predictions could be as accurate as weather forecasts, they probably would do more harm than good since they would create a wrong feeling of security and neglect of precautions . . . where no prediction has been made.

P. 467: It seems possible that . . . deep-focus earthquakes will lead to a revision of our ideas on the processes active before, during, and after the formation of mountain ranges. The facts already prove that layers much deeper than had been anticipated by most geologists are affected by such activity.

L. C. Graton, Ore Deposits. P. 473: The earliest geology was mining geology. . . . The very name *mineral* comes from *mine*.

P. 474: As regards geological theory and principle, the science of 1888 had acquired the essential form and content that it has today. Of the burning questions then, those that were regarded as fundamental would be so regarded now—and for the most part they still burn. P. 475: One great cause of disagreement was [and still is—Reviewer's note] the restricted field experience of the individual writers and the tendency of each to assume universal applicability for the particular explanation prompted by his own limited range of observation.

P. 474: . . . In studying ore deposits . . . resided the steadying consciousness of responsibility in putting geology to practical use . . .

P. 476: Revival of the connection between tectonic relationships and ore deposition is fortunately appearing. . . . Applause will be spontaneous when the first new mining district is located by such means.

P. 478: . . . Physiographic study has in several instances aided in showing the locus of concentration [of supergene ores].

P. 479: Mastery of this [the "geometry of folding"] and other structural problems has led to a fine record of ore finding by the Lake Superior iron companies. Taming of the previously unruly folds that guided mineralization in . . . South Dakota is . . . as fruitful scientifically as it is in dividends. . . . The "strain-ellipsoid" theory . . . helpfully fits the facts in many regions; but in some localities the fractures themselves seem rather unco-operative.

P. 480: . . . A depth below which ores could not be found. Reaction against views of this gloomy import gradually accumulated, as the idea of magmatic derivation gained ground. . . . Most convincing of all was the gradual extension of mining to very substantial depths on ores . . . whose deepest explored portions show little or no change from the shallower levels. . . . A recent estimate of something like 100,000 feet as a probable maximum depth-range of hydrothermal deposition. . . . P. 483: . . . Ores showing the characteristics ascribable to deep-seated formation are sure to be relatively old, because great erosion has been required to reveal them, whereas . . . the so-called bonanza ores . . . were formed close to the surface, and, as a rule, so recently that erosion has not had time to efface them—most of them are of late Tertiary age.

P. 487: For mastery of the ores, field work and ever more field work is utterly indispensable. Extreme caution must be exercised in following any treatise, no matter how pretentious, . . .; the postage stamp can never substitute for hobnails.

P. 496: As contrasted with the . . . hypogene deposits . . . the great supergene assemblage has occasioned far less controversy over fundamental principles and mechanisms of origin. P. 497: A substantial degree of agreement exists on the fundamentals, and the controversial residues relate mainly to subordinate matters. [For] The great examples of iron enrichment, . . . the conception of oxidation and of enrichment partly by direct addition and partly by wholesale removal of silica through . . . meteoric waters now finds little dissent.

P. 499: It is high time that geology should have a direct part in the finding of new mining districts.

An enormous amount of study . . . has been given to this subject [secondary sulphide enrichment] . . . Much emphasis has to fall on . . . restriction of the original proposals. P. 500: For copper, great exemplar of the process, the zone of supposed "oxide enrichment" was found to be the oxidized product of an enrichment accomplished as sul-

phide. The gloomy implication that below the chalcocite zone the protore . . . would invariably be lean . . . was shown . . . to be unjustified.

P. 501: Among the . . . placer deposits, . . . modern study emphasizes the relatively short distance between the source and the place of deposition. . . . Placer accumulations [are] insignificant in regions where the parent deposits, though rich, carry the gold or other metalliferous components in very tiny grains . . .

P. 503: . . . Opinion and practice go in waves wherein many suddenly embrace a conclusion or a technique that someone has proposed. In geology, the tendency to follow such leads as well as the tendency to dissent are more striking than in those sciences where experimentation invites prompt check. Dependent on one's personal point of view, these surges in geology are inspiring advances or futile fads. . . . It is necessary to wait for the slowly accumulating "weight of evidence"; and even this, when in times past accepted pretty widely on one topic or another, has often been later denied and displaced.

This is, assuredly, an undesirable situation. It is probably responsible in large measure for the sluggish current rate of advance in geology as compared with other sciences. . . . [Geology needs] improvement in the precision of our observations and especially in the quality of our logic. . . . We must tighten up our reasoning . . . Where speculation is unavoidable, let us appraise coldly its degree of *im*probability.

P. 505: . . . At least equally with all other geologists, he [the mining geologist] has the opportunity and the duty to contribute to the advance of pure science. P. 506: . . . A great and complicated ore body is a precious storehouse of truths which no company has a right to destroy without leaving for the future the fullest record that can within reason be secured and assembled.

P. 507: . . . The whole literature [of Economic Geology]. . . . The economic geologist. . . selecting from its enormous total. . . .

William B. Heroy, Petroleum Geology. P. 522: Most geologists will probably accept the thesis that petroleum has been formed at all times in the earth's past by the transformation of the then existing organic matter and that the distinguishing characteristics of the petroleum found in deposits of different ages are related to the nature of the particular organic matter present in the area where the petroleum was formed at the time of its origin.

P. 524: . . . Extensive chemical examination of recent marine sediments indicates that petroleum is not present in them and consequently is not formed at the time of deposition or shortly thereafter. P. 527: Older sediments of marine origin, both dense and porous, are impregnated with small quantities of petroleum, in contrast with recent sediments. . . . The statement seems justified that the conversion of the complex organic substances deposited with the sediments into the petroleum found in older rocks takes place within the source bed. . . .

P. 528: With the passage of time . . . a condition will ultimately be reached in which the compaction of the deeper beds will cease.

P. 530: . . . If the carrier bed does not have a surface outcrop, the excess waters deposited with the sediments will ordinarily have only one avenue of ultimate escape—across the bedding planes. It seems probable that most of the excess interstitial water must have passed upward through the section, for at the time when the basin was in formation and compaction was in process, the basin would usually not have been sufficiently deformed and eroded to provide the carrier beds with surface outcrops.

. . . Petroleum has moved from the source beds into the more porous beds throughout the entire extent of their contact. . . . In some manner the petroleum must have been collected from the wide areas throughout which it entered the porous beds and concentrated in the relatively much smaller areas which it is now found to occupy. [A footnote recognizes the opinion of a distinguished minority "that the accumulation of oil takes place essentially *in situ*. . . ."]

P. 531: A combination of the principles of flotation and hydraulic movement seems best to explain the movement of oil and gas to areas of accumulation. If globules of oil are put in motion in currents of water which are passing through porous rocks, they will at every opportunity seek a higher position. P. 534: The fundamental force which determines in what part of a carrier bed accumulation of oil and gas will take place is gravity.

P. 535: Accumulation occurs . . . because the upward and lateral movement of the oil and gas is arrested by the presence of a barrier. . . . P. 539: Many . . . fields through-

out the world could be mentioned as examples of involved conditions of accumulation but, to the extent that the facts have been ascertained, it has been found that the fundamental principle of buoyancy may be universally applied. . . .

P. 540: Traps which are formed during earlier periods of folding have an advantage over those which are formed later in the history of a basin. . . . We may accept the generalization of David White that the great migrations of oil and gas were accomplished mainly in periods of orogeny.

P. 541: . . . In some degree all oil deposits are subject to continuing dispersion.

P. 543: The basic principles announced a half century ago have been tested, evaluated, and amplified; the work of the fathers was so well done that little has been discarded. . . . Each unsolved problem challenges the attention of a new generation of investigators with fresh minds and new techniques. Large industrial and educational units are facilitating research. . . . The rate at which our knowledge of petroleum geology has advanced will be accelerated during the coming years.

Donald C. Barton, Exploratory Geophysics. P. 567: Very few geophysicists have paid any attention to refinement of the technique of interpretation [of magnetic data], and what they have learned has not appeared in the literature or become common knowledge.

P. 568: Ultimately . . . the electric method of logging oil wells . . . probably will be as important to the oil producing industry as all the rest of geophysics. . . . It gives the subsurface geologist . . . power . . . to make very much finer and more accurate correlations than he can make by the use of paleontological markers alone.

P. 569: In mining, . . . the success [of exploratory methods of geophysics] was far from as brilliant as . . . in petroleum work.

W. J. Mead, Engineering Geology. P. 573: . . . Essentially all phases of geology are brought into play in the practice of engineering geology. . . . Most of the geological reports [on applications of engineering geology] have been privately made and are unpublished and not available. . . . At the present time, geologists are employed . . . on all engineering projects of importance.

P. 574: . . . Many valuable scientific data have . . . been lost or buried in unpublished records. Geological information secured in the vast amount of preliminary exploration of foundations, dam and reservoir sites, tunnel, aqueduct, and canal locations, and other projects, and conditions disclosed during the actual carrying out of these projects, should be recorded and . . . made available through publication.

P. 577: In . . . coastal engineering . . . there has been an obvious lag in the application of geologic principles. . . .

P. 578; In the popular mind, soil erosion . . . is looked upon as a new type of infectious invasion . . . which must be stamped out by heroic measures. To the geologist, it is the operation of natural forces and processes as old as the rocks themselves.

That a serious deficiency exists in the military use of engineering geology is evidenced in part by the fact that no training in geology is offered in the courses of study for the United States Army Engineers at West Point.

THE TITUSVILLIIDAE; PALEOZOIC AND RECENT BRANCHING HEXACTINELLIDA, BY KENNETH E. CASTER

REVIEW BY W. A. VER WIEBE[1]
Wichita, Kansas

"The Titusvilliidae; Paleozoic and Recent Branching Hexactinellida," by Kenneth E. Caster. *Palaeontographica Americana* (Ithaca, New York, August, 1941), Vol. II, No. 12. 41 pp., 5 pls., 4 figs. Price $1.00, paper bound. Quarto.

In the 12th number of Volume II of the *Palaeontographica Americana*, Doctor Caster describes some of the interesting Paleozoic branching siliceous sponges found in New York. He points out that such sponges are rarities in

[1] University of Wichita. Manuscript received, October 22, 1941.

present seas and are even rarer in fossil form. Only a handful of the nodose branching Hexactinellida is known. The first member of the group was described by J. M. Clarke in 1918 and subsequently no mention was made of them until Caster described a near relative from the Mississippian rocks of Crawford County, Pennsylvania. The reason why these fascinating fossils have been neglected appears to lie in the fact that nearly all were collected as "worm burrows" and thus considered of slight importance.

Dr. Caster has re-examined all type materials which resemble his *Titusvillia drakei*, and has brought together all descriptions and illustrations in this publication. Most of the members of the family seem to be limited to upper Devonian and lower Mississippian horizons. Dr. Caster points out similarities to certain Recent sponges.

RECENT PUBLICATIONS

AUSTRALIA

*"Arenaceous Foraminifera from the Permian Rocks of New South Wales," by Irene Crespin and W. J. Parr. *Jour. and Proc. Royal Soc. New South Wales*, Vol. 74 (January 15, 1941), pp. 300–11; 2 pls. Published by the Society, Science House, Sydney. (Australia Geol. Survey, New Ser., Pub. 2.)

*"Paleontological Review of the Holland's Landing Bore, Gippsland," by Irene Crespin. *Min. and Geol. Jour.*, Vol. 2, No. 4 (March, 1941), pp. 252–56; 2 photographs of cores. Published by Victoria Dept. Mines, Melbourne. (Australia Geol. Survey, New Ser., Pub. 3.)

*"Geological Age of Caves Limestone, N. S. W.," by H. G. Raggatt. *Australian Jour. Sci.*, Vol. 3, No. 6 (June 6, 1941), pp. 170–71. (Australia Geol. Survey, New Ser., Pub. 4.)

CALIFORNIA

"Geology of California and the Occurrence of Oil and Gas," by many authors. *California Dept. Nat. Resources Div. Mines Bull. 118*, Pt. 2 (September, 1941). 195 pp., illus. 8.5×11 inches. This is Part Two of "Geologic Formations and Economic Development of the Oil and Gas Fields of California," prepared under the direction of Olaf P. Jenkins. Three parts compose *Bulletin 118*. Subscription price for complete bulletin, in preprint form, as each of the 3 parts is issued, $3.00. Order from Walter W. Bradley, State Mineralogist, Ferry Building, San Francisco, California.

*"Structural Notes on Recent Development of a Portion of Long Beach Field," by Wm. Ross Cabeen and M. K. M. Kelly. *California Oil World* Vol. 34, No. 18 (Los Angeles, 2d issue, September, 1941), pp. 2–8; 2 structure sections, 1 structure map.

CANADA

*"A Prospecting Programme for the Dominion," by Esme Eugene Rosaire. *Canadian Oil and Gas*, Vol. 2, No. 3 (Toronto, September, 1941), pp. 6–13.

*"Cascadia," by S. J. Schofield. *Amer. Jour. Sci.*, Vol. 239, No. 10 (New Haven, Connecticut, October, 1941), pp. 701–14; 2 figs.

GENERAL

The Mineral Industry during 1940, edited by G. A. Roush. Volume 49 of the annually compiled reference work on the statistics, technology, and trade of the mining and metallurgical fields, both foreign and domestic. 783 pp. Section on Petroleum and Petroleum Products, by Arthur Knapp. McGraw-Hill Book Company, New York (1941). Price, $12.00.

*"Neutron Well Logging: A New Geological Method Based on Nuclear Physics," by Bruno Pontecorvo. *Oil and Gas Jour.*, Vol. 40, No. 18 (Tulsa, September 11, 1941), pp. 32–33; 2 figs.

**Interpretation of Geologic Maps and Aerial Photographs*, by A. J. Eardley. 99 pp., 40 figs. Paper covers. 6×9 inches. May be ordered from the author, Department of Geology, University of Michigan, Ann Arbor, Michigan. Lithoprinted, 1941. Price, $1.50, postpaid.

*"Geological Interpretation of Regional Magnetic Anomalies in Central and Southern United States," by W. P. Jenny. *Oil Weekly*, Vol. 103, No. 3 (Houston, September 22, 1941), pp. 17–22; 1 folded map in colors.

*"Bibliography of Seismology, No. 9, January to June, 1941," by Ernest A. Hodgson. *Pub. Dominion Observatory*, Vol. XIII (Canada Dept. Mines and Resources, Ottawa, 1941), pp. 137–56; reference items 5011–34.

*"Report of the Committee on the Measurement of Geologic Time 1940–1941," Alfred C. Lane, chairman, and John Putnam Marble, vice-chairman. *Nat. Research Council Div. Geol. and Geogr.* (Washington, D. C., September, 1941). 121 mim. pp.

*"Gas Drive or Water Drive, and Is There a Radius of Drainage?" by Stanley C. Herold. *Canadian Oil and Gas*, Vol. 2, No. 3 (Toronto, September, 1941), pp. 15–16.

*"Petroleum Dynamics of the War," by Basil B. Zavoico. *Ibid.*, pp. 18–24.

*"Ionic Effects on the Rate of Settling of Fine-Grained Sediments," by L. R. Dreveskracht and G. A. Thiel. *Amer. Jour. Sci.*, Vol. 239, No. 10 (New Haven, Connecticut, October, 1941), pp. 689–700; 5 figs., 1 pl., 1 table.

*"Factors Involved in Submarine Core Sampling," by C. S. Piggot. *Bull. Geol. Soc. America*, Vol. 52, No. 10 (New York, October 1, 1941), pp. 1513–24; 3 pls., 3 figs.

*"Eruptivity and Mountain Building," by Bailey Willis and Robin Willis. *Ibid.*, pp. 1643–84; 2 pls., 9 figs.

*"Gravity Coring Instrument and Mechanics of Sediment Coring," by K. O. Emery and R. S. Dietz. *Ibid.*, pp. 1685–1714; 2 pls., 12 figs.

*"A Laboratory Study of Water Encroachment in Oil-Filled Sand Columns," by Frank G. Miller. *U. S. Bur. Mines R. I. 3595* (October, 1941). 32 mim. pp., 6 figs.

LOUISIANA

*"Geological and Geophysical Profiles through the Eola Field, Louisiana," by W. P. Jenny. *Oil and Gas Jour.*, Vol. 40, No. 18 (Tulsa, September 11, 1941), pp. 42–44; 2 figs.

*"Shallow Wilcox Accelerates North Louisiana Development," by M. M. Kornfeld. *Oil Weekly*, Vol. 103, No. 2 (Houston, September 15, 1941), pp. 16–25; 5 figs.

*"Northeastern Texas and Northwestern Louisiana," compiled by *Oil*

and Gas Jour., Vol. 40, No. 20 (September 25, 1941). 2 pp. between pp. 56 and 57; 1 sketch map and stratigraphic columns in colors.

NEW ZEALAND

"Oil-Shale Deposit of Orepuki, Southland," by R. W. Willett and H. W. Wellman. *New Zealand Jour. Sci. and Tech.*, Vol. 22 (2B), p. 84B (September, 1940). *Abstract in *Jour. Inst. Petroleum*, Vol. 27, No. 213 (Birmingham, England, July, 1941), p. 314A.

TEXAS

*"Fargo Field, Wilbarger County, North Texas," compiled by *Oil and Gas Jour.*, Vol. 40, No. 18 (Tulsa, September 11, 1941), pp. 24–25; 1 development map.

*"Northeastern Texas and Northwestern Louisiana," compiled by *Oil and Gas Jour.*, Vol. 40, No. 20 (September 25, 1941). 2 pp. between pp. 56 and 57; 1 sketch map and stratigraphic columns in colors.

*"Petroleum Engineering Study of the Anahuac Field, Chambers County, Texas," by Charles B. Carpenter and H. J. Schroeder. *U. S. Bur. Mines R. I. 3579* (August, 1941). 37 mim. pp., 15 figs., 11 tables.

*"Southwest Texas," compiled by *Oil and Gas Jour.*, Vol. 40, No. 22 (Tulsa, October 9, 1941). 2 pp. between pp. 52 and 53; sketch map and stratigraphic columnar sections in colors.

*"Lolita Field, Jackson County, Upper Texas Gulf Coast District," *ibid.*, pp. 93–94; 1 development map.

UTAH

"Geology of Area between Green and Colorado Rivers, Grand and San Juan Counties, Utah," by E. T. McKnight. *U. S. Geol. Survey Bull. 908* (July, 1941). 147 pp., 13 pls., 3 figs. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $1.50.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 11 (NOVEMBER, 1941), P. 2086

RESEARCH NOTES

THE ORIGIN OF OIL[1]

A. I. LEVORSEN[2]
Tulsa, Oklahoma

The research committee conducted a conference on April 5, 1941, at the Rice Hotel in Houston, on the subject, "The Origin of Oil." This was the day following the annual convention and the meeting continued from nine o'clock in the morning until nearly four o'clock in the afternoon. About 37 persons responded to the invitation and a stenotype report of the discussion was provided through the courtesy of the Houston Geological Society.

Many leaders in this field of investigation were present at the meeting, which was called to evaluate our present state of knowledge of this subject. The proceedings are in the nature of a progress report and it is believed that they will prove of interest to all who are interested in this problem.

The executive committee has published this report as a photolithographed booklet of 83 pages, 8½ inches by 11 inches. Copies can be had from Association headquarters, Box 979, Tulsa, Oklahoma, at a cost of $1.00 each, postpaid.

[1] Manuscript received, October 22, 1941.

[2] Chairman, research committee.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 11 (NOVEMBER, 1941), PP. 2087-2099, 2 FIGS.

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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(*Continued on page 2106*)

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		Warren B. Weeks

SUB-COMMITTEE ON CARBONIFEROUS

M. G. Cheney (1942), *chairman*, Coleman, Texas

1942	1943	1944
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	Norman D. Newell	Horace D. Thomas
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Henry C. Cortes (1944), *vice-chairman, geophysics*, Dallas, Texas
Carey Croneis (1943), *vice-chairman, paleontology*, Chicago, Illinois

1942	1943	1944
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Earl A. Trager	B. B. Weatherby	Kenneth K. Landes
		Paul Weaver

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COMMITTEE ON COLLEGE CURRICULA IN GEOLOGY

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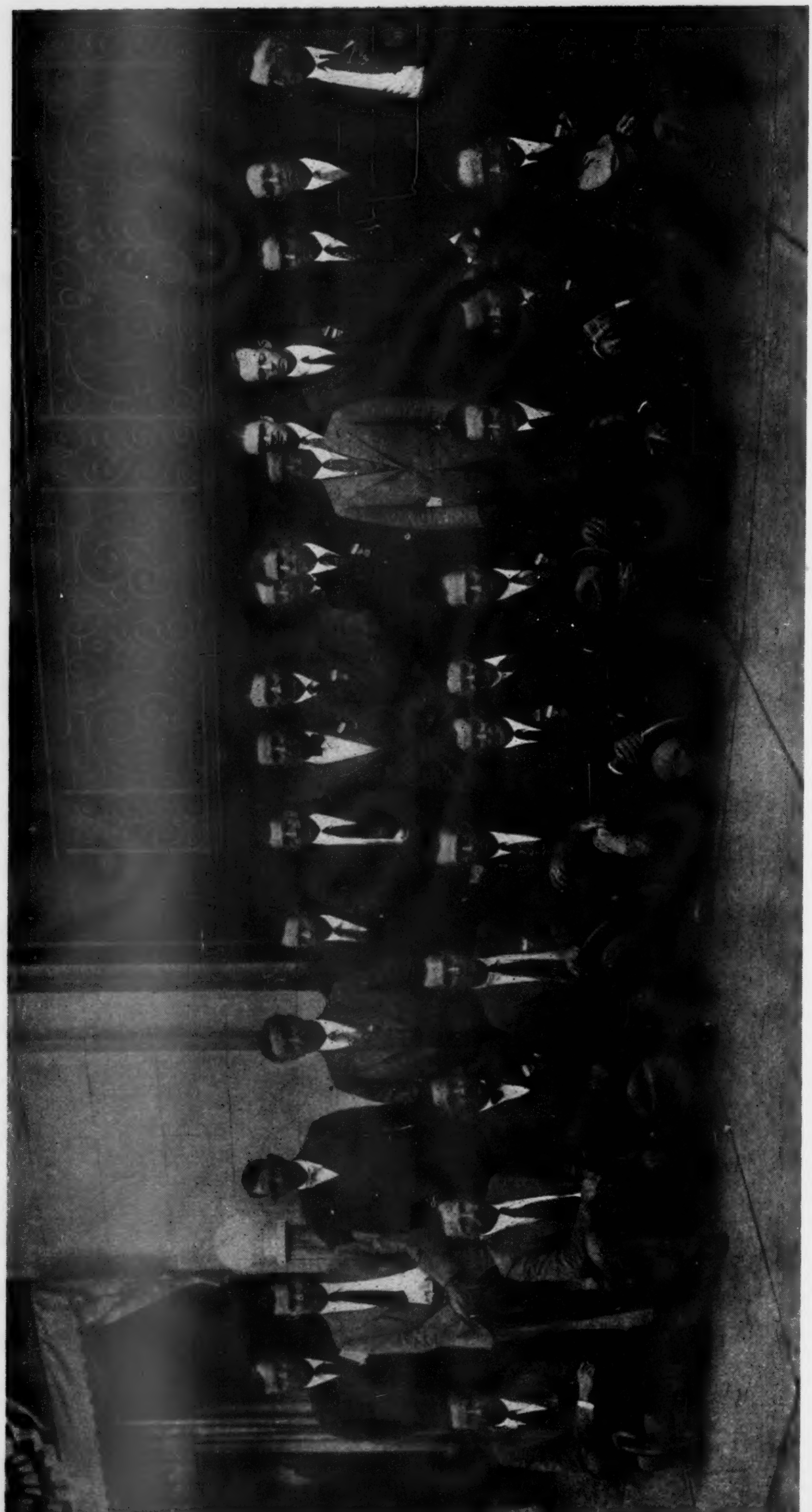
Hal P. Bybee	Henry A. Ley	W. T. Thom, Jr.
Ira H. Cram	John T. Lonsdale	

NATIONAL SERVICE COMMITTEE

Fritz L. Aurin, *chairman*, Southland Royalty Company, Fort Worth, Texas

Ben C. Belt	Frank A. Morgan	B. B. Weatherby
Eugene Holman		W. E. Wrather



Group of part of the fall meeting of the Association at the Cosmopolitan Hotel, Denver, September 20–24, 1926, photographed before going to the Fort Collins-Wellington oil field.

TWENTY-SEVENTH ANNUAL MEETING
DENVER, APRIL 21–24, 1942

The twenty-seventh annual meeting of the Association, to be held at Denver, Colorado, April 21–24, 1942, will follow the custom of several years in being a combined and concurrent convention of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists. The Hotel Cosmopolitan is convention headquarters. Chairmen of arrangements and committees selected by the host society, the Rocky Mountain Association of Petroleum Geologists, are the following.

C. E. Dobbin, general committee
A. E. Brainerd, technical program
H. A. Stewart, finance
H. W. Oborne, entertainment
C. S. Lavington, hotels
C. M. Rath, registration
J. W. Vanderwilt, West Slope trips
F. M. Van Tuyl, East Slope trips
T. S. Harrison, reception
W. A. Waldschmidt, publicity
W. O. Thompson, educational exhibits

In making plans for the Denver meeting, some of the 3,700 members of the Association will recall the fall meeting held there in 1926. Reproduced here is a picture of a group photographed in front of the Cosmopolitan, before going on a trip to the Fort Collins-Wellington oil field. If you can find yourself in this group, you may be an old-timer. Among others, are a president of the Association, an editor of the *Bulletin*, a State geologist of Oklahoma, and a director of the United States Geological Survey. A few shown in this picture have passed on.

The Rocky Mountain region is not a new oil petroliferous province. The Cañon City-Florence district is the second oldest oil producer in the United States. For the convenience of those desiring to recall the geology and the early-day romantic history, the following very brief list of publications is offered.

A FEW GUIDEBOOKS ON COLORADO AND ROCKY MOUNTAIN REGION

"Colorado," prepared under the direction of Charles W. Henderson. *XVI International Geological Congress (1933) Guidebook 19, Excursion C-1* (1932). 146 pp., 16 pls., 28 figs., 3 tables of geologic formations. A guidebook, plentifully illustrated, containing geologic road logs and bibliographies. Orders should be sent, *with accompanying remittance*, to the General Secretary, 16th International Geological Congress, c/o U. S. Geological Survey, Washington, D. C., but checks or money orders accompanying the order should be *made payable to the Treasurer, 16th International Geological Congress* (money orders on *Baltimore, Maryland* Post Office). Price, $0.40.

"Guide to the Geology of the Golden Area," by F. M. Van Tuyl, J. Harlan Johnson, W. A. Waldschmidt, James Boyd, and Ben H. Parker. *Colorado School of Mines Quarterly*, Vol. 33, No. 3 (Golden, July, 1938). 32 pp., 10 figs., 1 pl. (geologic map in colors). Contains selected bibliography. Colorado School of Mines, Dept. of Publications, Golden, Colorado. Price, $0.50.

"Guidebook of the Western United States. Part E. The Denver and Rio Grande Western Route," by Marius R. Campbell. *U. S. Geol. Survey Bull. 707* (1922). 265 pp., 96 pls., 63 figs. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $1.00.

Other issues of the Guidebook of the Western United States are the following.

Part A. "The Northern Pacific Route, with a Side Trip to Yellowstone Park." *Bull. 611* (1915). $1.00.

Part B. "The Overland Route, with a Side Trip to Yellowstone Park." *Bull. 612* (1915). $1.00.

Part C. "The Santa Fe Route, with a Side Trip to the Grand Canyon of the Colorado." *Bull. 613* (1915). $1.25.

Part D. "The Shasta Route and Coast Line." *Bull. 612* (1915). $0.50.

Part F. "The Southern Pacific Lines, New Orleans to Los Angeles." *Bull. 845* (1933). $1.00.

"Correlation of Geologic Formations between East-Central Colorado, Central Wyoming, and Southern Montana," by W. T. Lee. *U. S. Geol. Survey Prof. Paper 149* (1927).

"Geologic Map of the Front Range Mineral Belt, Colorado," by T. S. Lovering and E. N. Goddard. *U. S. Geol. Survey.*

Explanatory text for preceding map. *Colorado Sci. Soc.*, Vol. 14, No. 1 (1938).

"The Geologic Story of Rocky Mountain National Park, Colorado," by W. T. Lee. *National Park Service.*

"Guidebook, Twelfth Annual Field Conference along the Front Range of the Rocky Mountains, Colorado." *Kansas Geol. Soc.* (1938). 412 Union National Bank Building, Wichita, Kansas.

"Summary of Rocky Mountain Geology," by John G. Bartram. *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 8 (August, 1939), p. 1131.

"Ancestral Rockies and Mesozoic and Late Paleozoic Stratigraphy of Rocky Mountain Region," by Ross L. Heaton. *Ibid.*, Vol. 17, No. 2 (February, 1933), p. 109.

Colorado Symposium, *ibid.*, Vol. 17, No. 4 (April, 1933).

"Physiographic Development of the Front Range," by F. M. Van Tuyl and T. S. Lovering. *Geol. Soc. America*, Vol. 46, No. 9 (September, 1935), pp. 1291–1350.

"Relation of Paleozoic and Mesozoic Sedimentation to Cretaceous-Tertiary Igneous Activity and the Development of Tectonic Features in Colorado," by W. A. Burbank. In *Ore Deposits of the Western States* (Amer. Inst. Min. Met. Eng., Lindgren Volume, 1933).

A few historical or semi-fictional books are these.

Timberline, by Gene Fowler. Blue Ribbon Books Company. $1.00.

The Tabors, by Gandy. $3.75.

Silver Dollar, by Karsner. $1.00.

The Arkansas, by Clyde Brion Davis. American Rivers Series. Farrar and Rinehart, Inc., New York. $2.50.

PACIFIC SECTION EIGHTEENTH ANNUAL MEETING LOS ANGELES, OCTOBER 16–17, 1941. ABSTRACTS

The eighteenth annual meeting of the Pacific Section of the Association was held on October 16 and 17 at the Ambassador Hotel, Los Angeles. The technical and business sessions were conducted in the Ambassador Theatre. E. W. Galliher, president of the Section, presided at the first forenoon session, and Mason L. Hill, chairman of the program committee, Albert Gregersen, past-president of the Section, and E. R. Atwill, of the Union Oil Company of California, presided at the other half-day sessions. The attendance exceeded 400.

The opening address was delivered by Edgar W. Owen, president of the Association, who spoke of the increasing costs of exploration in recent years and consequent retardation in the search for new reserves of petroleum.

At the Thursday luncheon in the Cocoanut Grove, Basil B. Zavoico, of the Chase National Bank of New York, spoke on the subject, "Petroleum Orients the War." Members and guests numbered 157.

On Thursday evening, the Pacific Section of the Society of Economic Paleontologists and Mineralogists dined at the Clark Hotel and later listened to M. N. Bramlette speak on "Origin of the Sedimentary Rocks of the Monterey Formation." Frank Tolman was chairman at the S.E.P.M. meeting.

The annual dinner dance was held in the Fiesta Room of the Ambassador on Friday night. It was attended by 258 members and ladies.

Max L. Krueger was chairman of arrangements for this year's meeting.

The outgoing officers of the Section are: president, E. W. Galliher, Barns-

dall Oil Company; secretary-treasurer, E. J. Bartosh, Bankline Oil Company. Officers elected for the coming year are: president, E. J. Bartosh; secretary-treasurer, E. R. Atwill. New officers of the S.E.P.M. Section are: president, M. N. Bramlette; secretary-treasurer, Gilbert T. Bowen.

Titles and abstracts of the program follow.

ABSTRACTS

1. "Address by the National President of The American Association of Petroleum Geologists," EDGAR W. OWEN, of L. H. Wentz (Oil Division), San Antonio, Texas.

2. "An Introduction to the Cretaceous of California," OLAF P. JENKINS, State geologist of California, San Francisco.

Bibliographic history of the California Cretaceous, beginning with J. B. Trask in 1855, is briefly outlined. A list of the various Cretaceous units of the state is presented. Distribution of these rocks from the Oregon line to the Mexican border, from the Pacific Ocean to the foot of the Sierra Nevada, is indicated on a map of California, showing also the Cenozoic cover, and older basement rocks and Franciscan group. General thicknesses of the Cretaceous, taken at various points throughout the state, are shown on a map to give data for isopachs, which in turn indicate the possible positions of geosynclinal basins of deposition. Cretaceous economic products—building stone, gold, oil, and gas—are shown to be in direct relationship to major epochs in the geologic history of California.

3. "The Standard of the Cretaceous System," SIEMON W. MULLER and HUBERT G. SCHENCK, Stanford University.

The standard of the Cretaceous system represents a composite time-rock column—a total or complete sequence of strata between the Jurassic and the Cenozoic that can be recognized by distinctive fossils. This standard has been built up by fitting together continuous sections which are well exposed in different areas in Europe. The system is subdivided into series, stages, and zones. These divisions are based on paleontologic evidence, with no regard to thicknesses of strata and their lithologic character. One stage is described in detail to serve as an example demonstrating the methods employed in the establishment of a time-stratigraphic unit. The status of the boundaries between the underlying Jurassic and the overlying Cenozoic are discussed. In summary, the standard, provisional correlations with California are indicated.

4. "The Cretaceous Vertebrate Record of California," CHESTER STOCK, California Institute of Technology, Pasadena.

The Moreno shales exposed in the Panoche Hills and Tumey Hills of western Fresno County have yielded fossil fish and reptiles. Three major groups of Cretaceous reptiles are represented, namely, duckbill dinosaurs, plesiosaurs, and mosasaurs. Relationships of these reptiles are with Upper Cretaceous types. The Moreno, on the basis of vertebrate evidence, is assumably related in age to the Lance and Edmonton, and does not appear to be older than the Maestrichtian.

5. (a) "The Franciscan Knoxville Problem," N. L. TALIAFERRO, University of California, Berkeley.

The Franciscan is not a catch-all of uncertain age but a reasonably definite stratigraphic unit of known age. Both the Franciscan and Knoxville were deposited in a geosyncline which came into existence after the Nevadan orogeny. Both were deposited during the Tithonian stage of the Upper Jurassic. Minor disturbances occurred during their deposition, but they are not separated by an unconformity. In places, conditions which resulted in typical Franciscan lithology persisted until the close of the Jurassic so that Franciscan types in one locality are contemporaneous with typical Knoxville sediments in another locality.

(b) "Cretaceous of the Santa Lucia Range," N. L. TALIAFERRO, University of California, Berkeley.

The Cretaceous of the Santa Lucia Range falls into three major divisions, separated by profound unconformities. The Lower Cretaceous rests unconformably on the Franciscan, and is unconformably overlaid by the Upper Cretaceous. An even more widespread and profound unconformity occurs in the Upper Cretaceous. Upper Cretaceous sediments (Asuncion group) rest on lower Upper Cretaceous (Jack Creek formation) with an angular unconformity up to 70°, and overlap all older rocks, including the crystalline basement. The Asuncion group is the thickest and most widespread of all the divisions of the Cretaceous in the Santa Lucia Range.

6. "Cretaceous—West Side Sacramento Valley North of Willows," PHILIP W. REINHART, Shell Oil Company, Inc., Los Angeles.

The general features of the geology and stratigraphy, as determined from reconnaissance study, are discussed. Evidence is presented which indicates that the contact between the Knoxville and Franciscan is a fault having a displacement of many thousands of feet, resulting in the concealment of the basal Knoxville beds in the entire area. The stratigraphic sequence exposed along McCarthy and Elder creeks, Tehama County, is described, and the presence of occasional Foraminifera in the Mesozoic formations noted.

7. "Upper Cretaceous Stratigraphy of the West Side of Sacramento Valley South of Willows, Glenn County, California," JAMES M. KIRBY, Standard Oil Company of California, San Francisco.

This article discusses the lithology of the Upper Cretaceous sediments (Chico series) along the west side of Sacramento Valley as displayed in a series of measured and examined surface sections between Winters, Yolo County, and Willows, Glenn County. Certain recognizable lithologic units on the outcrop are described, defined, and named as a step toward the break-down of the thick Chico series into formations adaptable for use in this region. Variations in the outcrop sections, as well as between outcrop and strategically located well sections in Sacramento Valley, are shown by correlation charts and drawings.

8. "Cretaceous—East Side Sacramento Valley," W. P. POPENOE, California Institute of Technology, Pasadena.

Isolated outcrops of Upper Cretaceous beds are found in the lower stream

valleys, north, northeast, and east of Redding, Shasta County. The total thickness of the exposed beds aggregates 4,000 feet or more. Six well marked lithologic members, alternately predominantly sandstones and shales, may be recognized. The upper sandstones of Oak Run Valley, 2,500 to 3,000 feet above the base of the section, are the probable correlatives of the base of the Cretaceous section at Chico Creek 70 miles south.

9. "A Discussion of Part of the Upper Cretaceous Along the West Border of the San Joaquin Valley," A. S. HUEY and J. W. DALY, Shell Oil Company, Inc., Bakersfield.

Several stratigraphic sections of Upper Cretaceous rocks along the west border of the San Joaquin Valley are described, and correlations between the various units proposed. The relation of the type Moreno in Panoche Hills to the rocks which Anderson and Pack (*U.S.G.S. Bull. 603*) mapped as Moreno north of Pacheco Pass is discussed.

10. "Geology of the Del Valle Area," L. A. TARBET, Standard Oil Company of California, Los Angeles.

R. E. Havenstrite's Lincoln well No. 1 was the discovery well of the Del Valle oil field. Oil has been produced from the Jaspar Petroleum Company's Videgain well No. 1, 8,000 feet west of R. E. Havenstrite's Lincoln No. 1. Future development may be expected to join these two areas of production. The structural trap may be controlled on the north by a south-dipping fault, and on the east and south by the easterly and southerly plunge of the folded sediments. The trap on the west side of the field is obscured by a south-dipping fault. Lenticular oil sands, or minor faulting, may form the trap on the west side of the field.

11. "Geological Notes on the Oak Canyon Oil Field," WAYNE LOEL, consultant, R. W. CLARK, Western Gulf Oil Company, and PAUL P. GOUDKOFF, consultant, Los Angeles.

The Oak Canyon field is a plunging anticline with migration stopped, up the pitch, by a fault. Two sands have been developed. One, about 1,400 feet below the top of the Delmontian, is upper Mohnian and is older than the second sand in the Del Valle field. The lower sand is nearly 6,000 feet into the Miocene, and is probably in lower Mohnian. The top of the lower Mohnian is at about 3,290 feet in Lechler well No. 2. The top of the upper Mohnian is marked by an unconformity which appears to be both structural and erosional.

12. "Oil Fields—before Discovery and after Development," JAMES C. KIMBLE, General Petroleum Corporation, Bakersfield.

The interpretation which led to the discovery of fourteen California oil and gas fields are compared with post-development geology to illustrate the character of data necessary for discovery. Interpretations are depicted by means of structural and stratigraphic sections and structural contour maps with the use of approximately thirty-five slides. The fields discussed are representative of discoveries based on surface, subsurface, and seismic methods, and includes: Aliso Canyon, Buena Vista Gas, Canal, Coles Levee-Tupman area, East Coalinga-Eocene, Long Beach Extension, Padre Juan, Playa del

Rey, Potrero-Basin area, Rio Bravo, Newhall-Potrero, Santa Maria Valley, Seal Beach, and Wilmington.

13. "The Relationship between Some Types of Gravity Anomalies and Structure," ROBERT H. MILLER, Western Gulf Oil Company, Bakersfield.

A brief discussion of the principle of the gravimeter. Over many of the anticlinal structures in California gravity minima occur. Gravity disturbances of the same magnitude and extent would be set up by the warping of the relatively shallow beds during the growth of the fold. Shallow structure maps of some of the Central Valley fields show that the crests of the fold have collapsed under tension.

14. (a) "Some Drilling-Time Logs and Their Uses," ROBIN WILLIS, Hilldon Oil Company, Los Angeles.

Examples of drilling-time or rate-of-penetration logs, with corresponding electric logs, are shown to illustrate their use for progressive correlation while drilling, for checking depths of shooting intervals, and for interpreting electrical anomalies such as shells. Methods of taking them and their limitations are mentioned.

(b) "Northwest Extension of the Inglewood Field," ROBIN WILLIS, Hilldon Oil Company, Los Angeles.

Miocene production in the Northwest Inglewood field comes from 300 feet of lenticular sands below the nodular shale, on a southwest-dipping monocline closed by a large northeast-dipping overthrust which duplicates 200–500 feet of beds. Above this lies the shallower anticline of the Pliocene field, with many smaller thrusts recognizable in the electric logs, particularly on the northeast flank. The new zone is noteworthy for an exceptional formation pressure of about 5,000 pounds per square inch.

15. "Crocker Flat Infolded Landslide and Coarse Clastics in the Temblor Range, California," RUSSELL R. SIMONSON, Taft, and MAX L. KRUEGER, Union Oil Company of California, Los Angeles.

The Crocker Flat landslide, located in the vicinity of Recruit Pass northwest of Fellows, is composed largely of lower Miocene and Oligocene sands and silts, and a minor amount of middle Miocene shale, which were superimposed upon, and subsequently infolded in, younger Miocene sediments. This landslide mass descended by gravity, in upper Miocene time, from a highland located within or west of the San Andreas fault zone, prior to the deposition of the Santa Margarita (upper Miocene) fanglomerates. During Santa Margarita time, coarse clastics, derived from crystalline rock masses west of the Temblor Range, were deposited unconformably over the Crocker Flat landslide and adjacent area. The Santa Margarita beds, and the Crocker Flat landslide mass, were involved in the post-Miocene orogeny which elevated the Temblor Range and folded and faulted both of these units. Infolded and downfaulted outliers are the main areas of Santa Margarita sediments preserved from later erosion on the top of the range.

On the summit of the range, clastics, so coarse that they have been mapped as "Basement Complex" by several workers, are considered to be Santa Margarita in age because they are inter-tongued with, and grade

laterally into, sands and boulder beds containing Santa Margarita fossils in adjacent areas. Furthermore, parts of the landslid lower Miocene and Oligocene sediments of the Crocker Flat area are unconformably beneath these coarse clastics. This relationship also tends to preclude the premise of this "so-called basement" being a part of a huge overthrust sheet.

The crystalline rocks, mapped as "Basement Complex" on the west side of the range, are not in place but are detrital in origin and Santa Margarita in age also; these sediments owe their coarseness to the proximity of the source, and to possible minor landsliding during deposition.

The intercalated lenses of granitoid and schistose boulders and sands in the upper Miocene punky shales on the northeast side of the Temblor Range are equivalent in age to the coarse Santa Margarita fanglomerates on the southwest side of the Range. These beds are believed to have had a common western source, which must have been near at hand, within or west of the San Andreas fault zone. The erosional remnants of Santa Margarita fanglomerate along the summit, and higher parts of the Temblor Range, are regarded as being normally depositional in origin, and not klippen remnants of an overthrust sheet; these deposits represent an intermediate facies between the interbedded conglomerate and punky diatomaceous Santa Margarita on the northeast, and the coarse conglomerates on the southwest side of the range.

The Recruit Pass fault is a normal fault with its western side downthrown; it is thought to be one of the lines along which uplift occurred to give the present-day elevation of the Temblor Range.

16. "Radioactivity Well Logging through Casing," LOWELL C. BEERS, Lane-Wells Company.

The method of obtaining radioactivity logs is explained, and some correlation sections are illustrated to show applications of the method. The reactions of different lithologic units are shown, and certain theoretical considerations are presented to account for the radioactivity variations in sediments.

SUB-COMMITTEE ON TERTIARY[1]

JOHN G. BARTRAM[2]
Tulsa, Oklahoma

The committee on geologic names and correlations, at its last annual meeting in Houston, created a sub-committee to study the post-Cretaceous stratigraphy of the Gulf Coast area of the United States. A committee of ten has now been appointed for this purpose: W. Armstrong Price, chairman, Thomas L. Bailey, J. B. Garrett, Henry V. Howe, Wayne V. Jones, Gentry Kidd, Tom McGlothlin, Watson H. Monroe, Warren B. Weeks. One or two more may be added at a later date.

This sub-committee contains men who are non-members as well as members of the main geologic names and correlations committee. They have been selected to represent various areas of the Gulf Coast and various geological organizations as much as possible. The sub-committee is appointed for an ndefinite period and will report to the committee on geologic names and cor-

[1] Manuscript received, October 22, 1941.
[2] Chairman, committee on geologic names and correlations.

relations. It has been formed to review the present system of nomenclature and correlations of the Tertiary and Quaternary beds over the entire Gulf Coast area in the United States to determine whether the present system is adequate and proper. In this important province the petroleum geologists have done more detailed work on the stratigraphy and paleontology of the Tertiary and Quaternary rocks than has been done in any other area, with the possible exception of California.

Since much of the petroleum geologists' work is secret, they have not taken as large a part in the naming of formations and the division of the rocks on a regional scale as have geologists of the United States Geological Survey, the State surveys, and geological departments of universities. Unfortunately, all of the accumulated information of oil companies could not be available to other who have given names to strata. Many of the names were proposed long ago before the present detailed information had accumulated. It is now proposed that a competent group of petroleum geologists, representing geological organizations that have much of this detailed information or are familiar with it, and a representative from the United States Geological Survey, and one from the State surveys, review the entire set-up and report its findings. This is not a suggestion that the entire nomenclature be changed and radically altered, but it is to be a fact-finding review. It may be that many names are needlessly duplicated and that correlations can now be made that will eliminate surplus geologic names. The duty of the committee is to learn as much as it can about the problem and to try to determine what names and system of nomenclature will best serve the purpose of geologists' work in the Gulf Coast in years to come.

It is expected that this committee will coöperate fully with local geological societies and many of them may appoint their own local committees to work on the same problem in their immediate areas. No time limit has been placed on this project and work may continue for several years. It is asked that all members of the Association and other geologists assist the members of this committee as much as possible since they have a large and responsible task.

MEETING OF SECTION E, AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, DALLAS, DECEMBER 29–31

Headquarters of the American Association for the Advancement of Science will be the Adolphus Hotel, Dallas. Section E, Geology and Geography, will meet in Room 616, sixth floor of the First Baptist Church. The address of Hugh D. Miser, retiring chairman of the Section, "Quartz Veins in the Ouachita Mountains of Arkansas and Oklahoma," is scheduled for 11 A.M., Monday, December 29. The sessions, which in their entirety or in part are being held jointly with the Geological Society of America, the Association of American Geographers, the Texas Academy of Science, the Dallas Petroleum Geologists, and the Fort Worth Geological Society, include the following symposia.

Monday, December 29: Structure and Stratigraphy of the Southwest.

Tuesday, December 30, morning session, jointly with the American Geophysical Union: Relation of Geology to the Ground-Water Problems of the Southwest.

Tuesday, December 30, afternoon session, jointly with the Section on Anthropology: Early Man in North America.

Wednesday, December 31: Regional Geography of the Southwest.

A. C. Swinnerton, Antioch College, Yellow Springs, Ohio, is secretary of Section E.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 11 (NOVEMBER, 1941), PP. 2100-2101, 1 FIG.

Memorial

SAMUEL W. RITER

(1896–1941)

On August 5, 1941, Samuel W. Riter, 1547 S. Lewis Place, Tulsa, Oklahoma, died instantly as a result of a heart ailment. Death occurred near Rangely, Colorado, as he was assisting in a core analysis, part of an extensive geological field trip. Funeral services were held at his boyhood home, Logan, Utah, on August 9. He is survived by his widow, Mrs. Irene Riter; his mother, Mrs. Alice Riter, Logan, Utah; three brothers, Dr. Kernsey Riter, Logan, Utah, William Riter, Washington, D. C. and Randolph Riter, Denver, Colorado.

S. W. Riter was born at Logan, Utah, June 27, 1896. He attended the University of California in 1919 and 1920; the University of Utah in 1920 and 1921, receiving his B.S. degree in geology from that institution. He was a graduate student in geology and an instructor at the University of Chicago in 1921 and 1922 and at Stanford University in 1924.

After his formal education, Mr. Riter worked as a subsurface and reconnaissance geologist. He served in Mexico in 1922–1924, for the Mexican Gulf Oil Company; in Colombia, 1924–1925, for the Richmond Petroleum Company; and he was employed by the Venezuela Gulf Oil Company in Venezuela in 1925. Since that time he has served as geologist with the Gulf Oil Corporation, with headquarters at Tulsa, Oklahoma.

Riter was not only the son of patriots and pioneers, but a patriot and pioneer in his own right. He was for twenty years an active member of the Sons of the American Revolution. He served as a first sergeant in the Utah National Guard on the Mexican border in 1916, and as a first lieutenant in the 145th Field Artillery in France during World War I. He was a member of the American Legion.

Riter joined the Association in 1926. He was a member of the Tulsa Geological Society, Theta Tau (Eng.), American Association for the Advancement of Science, Sigma Xi, Pi Kappa Alpha—Gamma Alpha. In addition, he devoted much time to Masonic work, being an active member of Delta Lodge 425 A. F. & A. M., Tulsa Chapter No. 52 and Trinity Commandery No. 20 of Tulsa.

Although "Sam" Riter's death was untimely, his family and friends are comforted by the thought that after years crowded with experiences few are privileged to enjoy, lived to the full, he died quietly and peacefully, at the height of his powers, while doing the work which he keenly enjoyed. It is fitting that death should have reached him in the shadow of the western mountains which he loved so well, almost at the scene where his pioneer forefathers helped to build an empire. His rugged honesty in thought and deed, his unfailing friendliness and generosity, his zest for living, will long be remembered by those who knew him best.

D. G. EMRICK

TULSA, OKLAHOMA
August 18, 1941

OTTO LEATHEROCK

(1901–1941)

The passing of Otto Leatherock on October 3, 1941, at his home, 4632 South Vancouver, Tulsa, Oklahoma, after an illness of a year and a half, will be mourned by his many friends throughout the Mid-Continent area.

He is survived by his widow, Esther Hall Leatherock; a son, Harold, and a daughter, Wilma; his parents, Dr. and Mrs. R. E. Leatherock of Cushing, Oklahoma; three sisters, Mrs. H. K. Ward of Los Angeles, California, Constance Leatherock of Tulsa, and Mrs. W. J. Foster of Tulsa; and a brother, Walter Robbins of Roosevelt Dam, California.

OTTO LEATHEROCK

Mr. Leatherock was born at Mountain View, Oklahoma, on November 10, 1901. He finished High School at Drumright, Oklahoma, in 1920, and in the fall of 1924 he entered the University of Oklahoma. He graduated from the University in the spring of 1928, with a degree in petroleum engineering. From May, 1928, until December, 1928, he was employed by the Indian Territory Illuminating Oil Company at Bartlesville, Oklahoma, as a magnetometer operator. In January, 1929, he was employed by the Sinclair Oil and Gas Company, as geologist, and remained in the employ of that company until March, 1931. From June, 1934, to April, 1935, he was employed as geologist by the United States Geological Survey, Tulsa, Oklahoma, and while serving in this capacity he was the co-editor of U. S. G. S. Bulletins 900A, 900B, 900E, 900F, and 900H. In December, 1935, he was employed by the Oklahoma Geological Survey at Norman, Oklahoma, as geologist, and held that position until February, 1937. In March, 1937, he was employed by the Olson Oil Company, Tulsa, Oklahoma, as geologist, and remained in that capacity until his death, October 3, 1941.

Mr. Leatherock was a member of Sigma Gamma Epsilon, honorary geological fraternity; the American Association of Petroleum Geologists; and a former member of the Oklahoma City Geological Society.

The Olson Oil Company has lost a valuable and devoted member, and his host of friends whom he acquired while in the field and in the office will in no small way miss him.

J. B. HOOVER

TULSA, OKLAHOMA
October 19, 1941

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 11 (NOVEMBER, 1941), PP. 2102-2106

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

E. O. BUCK, assistant deputy petroleum coordinator of Houston, Texas, spoke on "Functions of the Office of Production Coordinator" before the Shreveport Geological Society, October 3.

CLENON C. HEMSELL, Columbian Fuel Corporation, Amarillo, Texas, was the speaker at the Tulsa Geological Society meeting, October 6. His subject was "Subsurface Conditions in Texas County, Oklahoma."

ATLEE G. MANTHOS, who has been assistant to WILLIS STORM, consulting geologist, San Antonio, Texas, for several years, is now an aviation cadet in the U. S. Air Corps with the Air Corps Training Detachment at Hicks Field, Fort Worth, Texas.

W. E. WRATHER, consulting geologist and operator of Dallas, Texas, past-president of the Association, was one of eighteen, of the 45,000 alumni of the University of Chicago, awarded medals for distinctive service in the field of science and in civic affairs. The presentation was part of the fiftieth anniversary celebration of the University in September.

STANFORD L. ROSE, of the Standard Oil Company of California, now stationed at Tulsa, who returned from India a few months ago, spoke before the Tulsa Geological Society first fall luncheon, September 25, on conditions in that country.

JOHN C. MILLER, of The Texas Company, Houston, Texas, spoke on "Well Spacing and Production Interference in the West Columbia Field, Brazoria County, Texas," at a meeting of the Houston Geological Society, September 25.

H. C. WHEELER, geologist and operator of Midland, Texas, was killed, and WALLACE W. IRWIN, of Culbertson and Irwin, also of Midland, was injured in an automobile accident near Jal, New Mexico, September 19.

C. W. TOMLINSON talked before the Ardmore Geological Society, at Ardmore, Oklahoma, October 1, on the 50th anniversary volume of the Geological Society of America, "Geology 1888–1938."

HAROLD G. PICKLESIMER, recently with the Arkansas Geological Survey at Little Rock, has accepted a position in the exploration department of the Arkansas Fuel Oil Company at Shreveport, Louisiana.

JOHN J. COLLIER, JR., is in the geological department of The Pure Oil Company at Houston, Texas.

GEORGE H. CLARK, of The Texas Company, has been transferred from Houston to the Louisiana-Arkansas division with headquarters in New Orleans. His new residential address is 4653 Spain Street, New Orleans, Louisiana.

JOHN D. MOODY is on leave of absence from the Gulf Refining Company, Shreveport, Louisiana, and is now on duty as a lieutenant in the Marine Corps at Quantico, Virginia.

DAVID T. HOENSHELL, recently with the Kettleman North Dome Association, Avenal, California, is now with the Trinidad Leaseholds, Ltd., Pointe-a-Pierre, Trinidad, B.W.I.

ROBERT H. DOTT, Norman, director of the Oklahoma Geological Survey, gave a summary of a paper, "Regional Stratigraphy of Mid-Continent," before the Shawnee Geological Society at the September meeting.

WARREN W. MANKIN, recently with the Oklahoma Natural Gas Company, at Tulsa, is on active duty as First Lieutenant in the Air Corps Technical School, Sheppard Field, Wichita Falls, Texas.

J. P. JONES, of the Arkansas Fuel Oil Company, has moved from McAllen, Texas, to Shreveport, Louisiana.

Cadet STERLING E. LITTLE may be addressed at Room 150, Building 711, Naval Air Base, Jacksonville, Florida. He was recently with the William Helis Oil Company, New Orleans, Louisiana.

HEDWIG T. KNIKER, recently independent paleontologist, has closed her laboratory in the Alamo National Building, San Antonio, Texas, and can now be reached at her residence, 134 West Agarita Avenue, in that city.

S. K. VAN STEENBERGH, of the Brown Geophysical Company, has moved from Kansas to Houston, Texas.

T. F. HARRISS, of the California Arabian Standard Oil Company, formerly stationed at Bahrein Island, Persian Gulf, may be addressed in care of the company at 200 Bush Street, San Francisco, California.

STUART K. CLARK, assistant chief geologist for the Continental Oil Company, Ponca City, Oklahoma, spoke on "Wide Well Spacing-Panacea or Delusion," before the South Texas Geological Society at San Antonio, October 3.

New officers elected by the Shreveport Geological Society, Shreveport, Louisiana, are: president, JAMES D. AIMER, Arkansas Fuel Oil Company; vice-president, JOSEPH PURZER, Phillips Petroleum Company; secretary-treasurer, VAN D. ROBINSON, Atlantic Refining Company. The society meets on the first Friday of every month, 7.30 P.M., Civil Courts Room, Caddo Parish Court House.

JOHN F. MASON, recently in the department of geology at Princeton University, is in the department of earth sciences at the University of Pennsylvania, Philadelphia, Pennsylvania.

The Houston Geological Society has elected the following officers for the year 1941–1942: president, CARLETON D. SPEED, JR., consulting geologist, Second National Bank Building; vice-president, DONALD M. DAVIS, Pure Oil Company, Esperson Building; secretary, WAYNE Z. BURKHEAD, Union Oil Company of California, 1134 Commerce Building; treasurer, JAMES W.

KISLING, JR., Amerada Petroleum Corporation, Esperson Building. Members of the advisory committee are: HERSHAL C. FERGUSON, independent geologist; CARL B. RICHARDSON, Barnsdall Oil Company; M. H. STEIG, Phillips Petroleum Company; all in the Esperson Building. Regular meetings are held every Thursday at noon, Mezzanine floor, Texas State Hotel.

The following are the newly elected officers of the East Texas Geological Society, Tyler, Texas, for the current year: president, C. I. ALEXANDER, Magnolia Petroleum Company; vice-president, E. B. WILSON, Sun Oil Company; secretary-treasurer, L. BRUNDALL, Shell Oil Company, Inc.

C. R. MCKNIGHT, of the geological department of Arkansas Natural Gas Company, Shreveport, Louisiana, has begun his eighth year as supervisor of the Centenary Night School which is a branch of Centenary University. McKnight has also regularly taught courses in geology.

R. P. LOCKWOOD, formerly of Parkersburg, West Virginia, is geological observer for Gulf Oil Corporation at Calgary, Alberta, Canada.

PAUL J. FLY, formerly with the Mar-Tex Oil Company, has resigned and opened offices as consulting geologist in the Esperson Building, Houston, Texas.

The Oklahoma City Geological Society has elected officers as follows: president, RICHARD W. CAMP, Consolidated Gas Utilities Corporation; vice-president, D. A. MCGEE, Kerlyn Oil Company; and secretary-treasurer, H. TRAVIS BROWN, I.T.I.O. Company.

FRED H. MOORE, of the Magnolia Petroleum Company, has moved from Youngstown, Ohio, to Wichita Falls, Texas.

The Mississippi Geological Society, Jackson, Mississippi, has elected new officers: president, TOM MCGLOTHLIN, Gulf Refining Company; vice-president, DAVID C. HARRELL, Carter Oil Company; secretary-treasurer, A. A. HOLSTON, Stanolind Oil and Gas Company, Box 689. Meetings are held on the first and third Wednesdays of each month at 7:30 P.M., Edwards Hotel, Jackson.

JOHN R. SUMAN, president of the American Institute of Mining and Metallurgical Engineers, spoke before the Colorado Section of the A.I.M.E. and the Rocky Mountain Association of Petroleum Geologists at Denver, Colorado, October 20, at an informal dinner meeting.

J. A. MULL, JR., of the Republic Natural Gas Company, Hugoton, Kansas, spoke before the Tulsa Geological Society, October 20, on "Stream Channels Applied to the Arbuckle of the Central Kansas Uplift."

ROY J. METCALF, geologist with the Ohio Oil Company at Houston, Texas, died on October 6.

URBAN B. HUGHES, consulting geologist, announces the removal of his office to 105½ West Capitol Street, West Jackson, Mississippi, and the opening of his office in Laurel, Mississippi, in the Mississippi Drug Building. His post-office address is Box 2476, West Jackson, Mississippi.

W. L. RUSSELL, of Well Surveys, Inc., Tulsa, Oklahoma, spoke on "New Methods of Geophysical Well Logging," before the Rocky Mountain Association of Petroleum Geologists, at Denver, Colorado, October 6.

JOHN R. SUMAN, vice-president of the Humble Oil and Refining Company, Houston, Texas, was presented a distinguished service award of the Texas Mid-Continent Oil and Gas Association last month.

GEORGE SAWTELLE, president of the Kirby Petroleum Company, Houston, Texas, was elected president of the Texas Mid-Continent Oil and Gas Association in October.

LYMAN C. DENNIS, recently with the Pure Oil Company of Olney, Illinois, has been appointed district geologist for that company at Clay City.

The 54th annual meeting of The Geological Society of America, H. R. ALDRICH, secretary, 419 West 117th Street, New York, will be held December 29–31, at the Hotel Statler, Boston, Massachusetts, under the auspices of the Geological Society of Boston, the Massachusetts Institute of Technology, and Harvard University. The address of the retiring president, CHARLES P. BERKEY, will be delivered on December 29. Associated societies which will hold meetings in conjunction with the Geological Society are the following: The Paleontological Society, 33d annual meeting, secretary, H. E. VOKES, American Museum of Natural History, New York; The Mineralogical Society of America, 22d annual meeting, secretary, PAUL F. KERR, Columbia University, New York; The Society of Economic Geologists, 22d annual meeting, secretary, W. D. JOHNSTON, JR., U. S. Geological Survey, Washington, D. C.; The Society of Vertebrate Paleontology, 1st annual meeting, secretary, GEORGE G. SIMPSON, American Museum of Natural History, New York. The Geological Society of America will join with Section E of the American Association for the Advancement of Science, the Texas Academy of Science, and the Association of American Geographers in sponsoring the meetings to be held in Dallas, Texas, December 29–31. HUGH D. MISER as retiring vice-president of Section E will deliver the principal address: "Quartz Veins in the Ouachita Mountains of Arkansas and Oklahoma."

H. STAUFFER has retired from the service of the Shell Oil Company, Inc., after 22 years of tropical service and has settled permanently in California at 544 Lowell Avenue, Palo Alto.

GRAYSON E. MEADE, formally of the Bureau of Economic Geology of the University of Texas, has joined the faculty of Texas Technological College, Lubbock, as instructor and research assistant in vertebrate paleontology.

HORACE C. DAVIS, of Austin, Texas, may be addressed at Puerto Cabezas, Nicaragua.

R. M. STAINFORTH is doing geological work with the Trinidad Leaseholds, Ltd., Pointe-a-Pierre, Trinidad, B. W. I.

From October to December, 1941, the Fort Worth Geological Society and the Fort Worth Petroleum Engineer's Club are holding a ten-weeks seminar course on: "Development, Operation, and Valuation of Oil and Gas Properties." Texas Christian University has donated the use of class room facilities

for weekly night meetings. PARK J. JONES, of the engineering staff of the Texas Company, prepared the text for this course and delivers the lecture and leads the discussion at each of the weekly meetings. The text for this course, which consists of 150 pages, includes 17 pages of appraisal tables and numerous diagrams. Ten topics will be discussed in the following order: (1) Effective porosity, specific permeability, and the geometry of spacing; (2) Flow of homogeneous fluids through linear systems; (3) Flow of homogeneous fluids through radial systems; (4) Water in virgin oil and gas "pays"; (5) Flow of oil-water mixture through media of uniform permeability; (6) Flow of gas-oil mixtures through media of uniform permeability; (7) Flow of gas-oil-water mixtures through media of uniform permeability; (8) Behavior of natural gases; (9) Behavior of gas-oil mixtures; (10) Estimating oil reserves from production decline rates. A limited number of copies of the text is available and may be purchased from the Fort Worth Geological Society for $2.50. Requests should be addressed to WILLIAM J. HILSEWECK, Box 1290, Fort Worth, Texas.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

(Continued from page 2087)

Alan John Grobecker, Pasadena, Calif.
Ian Campbell, John P. Buwalda, John J. Rupnik
Banhart Pete Harder, Henrietta, Tex.
Hal P. Bybee, Leo Hendricks, Robert H. Cuyler
William James Hendy, Jr., Vicksburg, Miss.
E. F. Schramm, E. C. Reed, H. N. Fisk
Eric Howard Jager, Wichita, Kan.
Hal P. Bybee, Fred M. Bullard, Kirtley F. Mather
David Kemp Langford, Wichita Falls, Tex.
John A. Kay, Paul E. M. Purcell, H. F. Smiley
Jesse William Marshall, Tulsa, Okla.
Myron C. Kiess, Stewart Cronin, Joseph L. Borden
William Raymond Merrill, Ventura, Calif.
Claude E. Leach, F. A. Menken, H. J. Steiny
Nelson Pierce Stevens, Dallas, Tex.
William W. Clawson, Henry C. Cortes, Fred E. Joekel
Frederick Morrill Swain, Shreveport, La.
Raymond C. Moore, Kenneth K. Landes, Norman D. Newell
Elizabeth Anne Watson, Los Angeles, Calif.
Hubert G. Schenck, Elmo W. Adams, A. C. Waters

FOR TRANSFER TO ACTIVE MEMBERSHIP

George Henry Crowl, Princeton, N. J.
P. E. Nolan, K. C. Heald, Philip Andrews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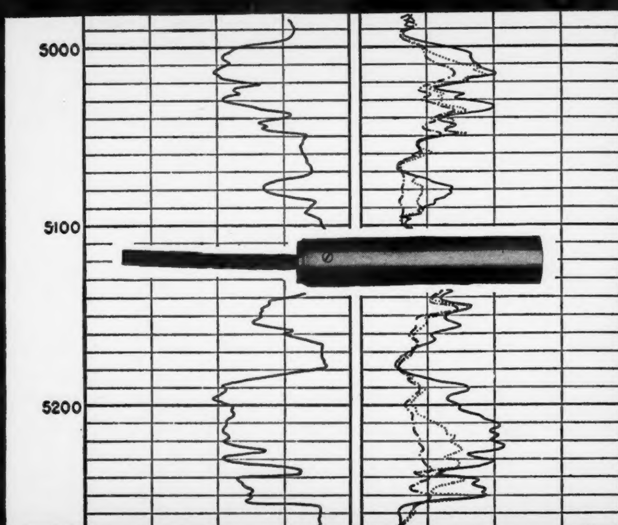

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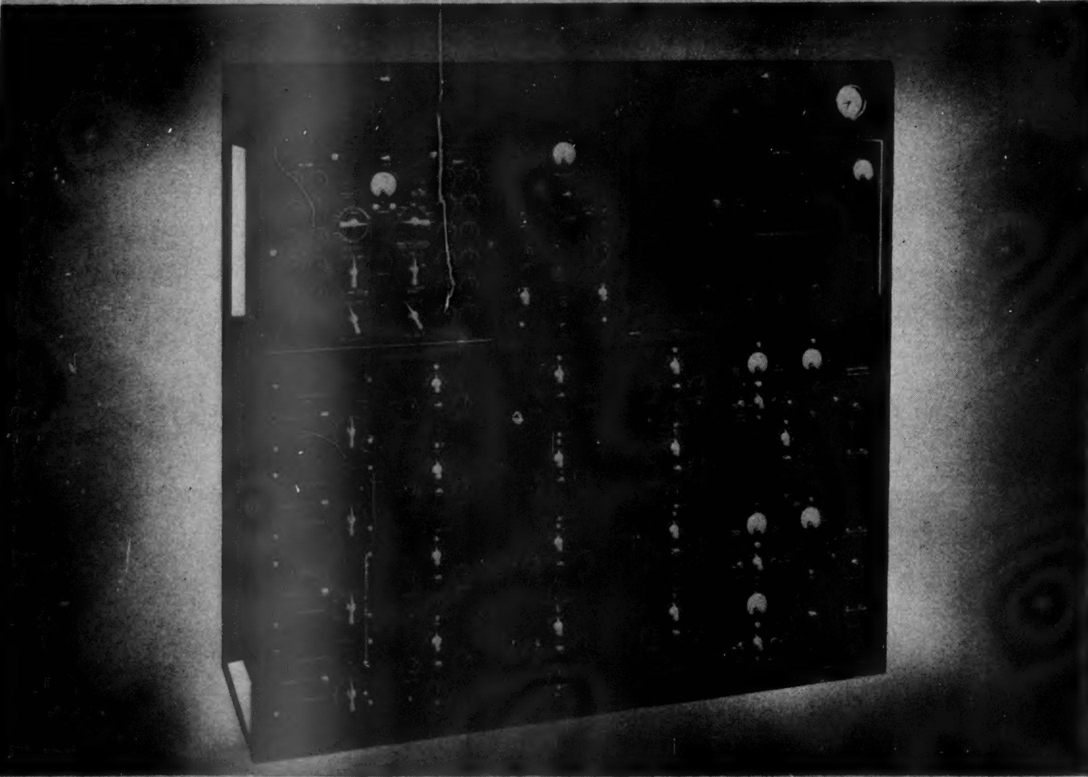


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